JAN 5 1925

Volume VIII Number 6

BULLETIN

of the

American Association *of* Petroleum Geologists

NOVEMBER-DECEMBER
1924

RAYMOND C. MOORE
EDITOR

PUBLISHED BY THE ASSOCIATION
CHICAGO, ILLINOIS

COPYRIGHT, 1924, BY THE AMERICAN ASSOCIATION
OF PETROLEUM GEOLOGISTS

SHAFFER OIL AND REFINING COMPANY

Room 729 Kennedy Bldg.
TULSA, OKLA.

Producers, Refiners, Shippers, and Marketers of

GOES FARTHER
DEEP-ROCK
LASTS LONGER

Gasoline	Non-Viscous Neutral
Naphtha	Viscous Neutral
Kerosene	Paraffine Wax
Gas Oils	Greases

Fuel Oils

Assorted Carloads of Mixed Lubricating Oils and Greases

We Solicit Your Patronage Upon
The Merits of Deep Rock Products

Sales Department
1018 S. Wabash Ave.
Chicago, Ill.

Refinery
CUSHING, OKLA.

Volume VIII Number 6

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

NOVEMBER-DECEMBER 1924

MIGRATION OF OIL AND WATER, A FURTHER DISCUSSION[1]

E. M. PARKS
Denver, Colorado

INTRODUCTION

It has been urged that experimental data and accurate field evidence are more needed than theories in petroleum geology. Perhaps so, yet the most enthusiastic experimenters are sometimes most concerned with proving a theory. The facts which we need to know are so complex, the time involved so great, and the bodies of rock so large that without working hypotheses to guide us we should grope blindly in experiment. There is no ruling theory in petroleum geology except that oil and gas in most cases occur in certain structural relations and that in a particular region a certain structural habit is to be expected. This is purely empirical, and every driller tells us: "Oil is where you find it."

Our explanations for the various types of occurrences are merely working hypotheses; we have a multiple working hypothesis method of investigation. This multiple-hypothesis stage of speculation was started by Munn and Shaw.[2] Their experiments were simple, but enough to lead them into new paths. Most of the

[1] Paper read by title before the Los Angeles meeting of the Association, September, 1923. Manuscript received by the Editor, December, 1923.

[2] M. J. Munn, "Studies in the Application of the Anticlinal Theory of Oil and Gas Accumulation," *Econ. Geol.*, Vol. 4 (1909), pp. 141–57; "The Anticlinal and Hydraulic Theories of Oil and Gas Accumulation," *ibid.*, pp. 509–29.

E. W. Shaw, "Crevices and Cavities in Oil Sands," *ibid.*, Vol. 13 (1918), pp. 207–25. This contains a useful bibliography.

hypotheses regarding diastrophic origin and accumulation of oil,[1] capillary segregation,[2] and flushing[3] are directly traceable to Munn's hydraulic theory.

So far no one has fused the various speculations into a coherent whole. Rich's idea of accumulation by flushing downward has little in common with Daly's migration by dynamic forces. Munn assumed ground-water movements of high pressures and did not examine the causes of circulation at much length. Washburne supposes that the high pressures in oil and gas sands come from high pressures far below the zone of accumulation. Some evidently suppose there is little migration until considerable bodies of oil are collected together, others that microscopic globules of oil and gas migrate as the water listeth. Some suppose the oil is deposited as oil in the muds and sands,[4] others that it originates chiefly during times of horizontal compression. Most of us suppose the mother-material was laid down chiefly in muds, but a few think enough of it to explain known accumulations was present in the sands themselves, and some of us are becoming uncertain as to how much mother-material is necessary, or how to recognize it. Migration upward into reservoirs above the source is in general assumed, but many are careful to grant the possibility of downward migration. That oil, when first formed, is heavy has been suggested by David White,[5] while Washburne is committed to the idea that the lighter hydro-

[1] Marcel R. Daley, "The Diastrophic Theory," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 56 (1916), pp. 733–81; "Geosynclines and Petroliferous Deposits," *ibid.*, Vol. 57 (1918), pp. 1054–70.

David White, "Late Theories Regarding the Origin of Oil," *Bull. Geol. Soc. Amer.*, Vol. 28 (1917), pp. 727–34; "Genetic Problems Affecting Search for New Oil Regions," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 65 (1921), pp. 176–99.

[2] C. W. Washburne, "The Capillary Concentration of Gas and Oil," *ibid.*, Vol. 50 (1915), 829–59; discussion of "Some Effects of Capillarity in Oil Accumulation," *Jour. Geol.*, Vol. 25 (1917), pp. 584–87.

[3] J. L. Rich, "Moving Underground Water as a Primary Cause of Migration and Accumulation of Oil and Gas," *Econ. Geol.*, Vol. 16 (1921), pp. 347–71; "Further Notes on the Hydraulic Theory of Oil Migration and Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 213–36.

[4] Murry Stuart, *Records, Geol. Sum. Ind.*, Vol. 40, Part 4 (1910), pp. 320–33, reviewed in *Econ. Geol.*, Vol. 7 (1912), pp. 92–95, by David White.

[5] David White, *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 65 (1921), p. 186.

carbons unite to form the heavier.[1] Whether the chemical changes that take place in nature as oil goes through its cycle of formation and destruction are mainly exothermal or endothermal is not established, although certain field phenomena indicate that it may be chiefly exothermal.[2]

The writer does not believe that any general account of the history of an oil pool, how and when it originated, and by what agencies it reached its present position, can yet be written, and so hastens to disclaim any ambition of adding a new and complete theory. If any ideas are advanced which have already been suggested, they may be attributed to others who have pioneered in the field, although they have been developed largely independently. It is often difficult to know whether one's ideas on a subject like this have been suggested by something read, or by one's own thinking. More experiments like those of Mills, McCoy, Cook, Day, and others are needed and will eventually lay all false theories "on the shelf," as Professor Chamberlin expresses it. Determination of many physical facts like the compressibility of oils, solubilities of gas in oil and water under moderately high pressures, viscosity of natural oils under pressures, effect of dissolved gases on viscosity, etc., are greatly needed. G. S. Rogers indicated an important phase in his discussion of the relation of viscosity to the chemical character of ground waters.

That oil migration and accumulation are intimately connected with the history of ground-water circulation will readily be granted by all. That it is more closely connected than generally supposed is the main contention here. The causes of ground-water migration and its probable history will be examined, which leads to significant conclusions on the relation of this history to oil formation and accumulation.

DEFINITIONS

By *migration* is meant movements through a considerable distance, even many miles in some cases.

[1] C. W. Washburne, *ibid.*, Vol. 50 (1915), p. 854.

[2] G. S. Rogers, "Relations of Sulphur to Variation in the Gravity of California Petroleum," *Trans. Amer. Inst. of Min. Met. Eng.*, Vol. 57, pp. 989–1010; "Chemical Relation of Oil Field Water in San Joaquin Valley, California," *U. S. Geological Survey Bull. 653*, 1917.

Segregation is used for smaller movements that result in oil and gas rising to the top of the sand after reaching the place of accumulation.

By *metamorphic circulation*[1] is meant the circulation of waters which are mainly, but not wholly, connate waters, this circulation being due to compacting of sediments and reduction in pore space by whatever cause.

By *artesian circulation* is meant the circulation of waters that are mainly or wholly meteoric, due to higher ground-water surface in some places, the most general cause being downward percolation of meteoric water.

Capillary circulation is the movement caused by differences in capillarity in an oil-water or oil-water-gas system. The importance of this in segregation has been urged by Washburne, but will not be discussed.

By *periodic circulation* (or movements) will be understood the to-and-fro movements, due to barometric changes, tidal action, earthquake shocks, or any other cause tending to produce oscillation of ground waters. These movements have never been thoroughly inquired into, but may be of greater importance in inducing segregation than all other circulation but of less importance in migration. While some of these movements are not strictly periodic, no better term has suggested itself.

Induced circulation[2] means circulation set up during the development of oil fields.

Other causes of circulation such as heat exchange, elevation or depression without accompanying metamorphism, the escape of gas, expansion of fluids by erosion and lowering of ground-water table, and changes in weight of overlying column of water by migration of waters of different densities may be mentioned. Some affect ground water to depths that would influence oil accumulation; others do not.

[1] The writer is indebted to E. Russell Lloyd for this term.

[2] R. Van A. Mills and R. C. Wells, "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U. S. Geological Survey Bull. 693*, 1910. R. Van A. Mills, "Natural Gas as a Factor in Oil Migration and Accumulation in the Vicinity of Faults," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 14–24.

Lateral circulation is used to denote circulation approximately parallel to bedding planes. It may accordingly proceed in any direction in the plane of dipping beds.

Transverse circulation is used to denote circulation across bedding planes and may be in any direction.

This paper will dwell on the metamorphic and artesian circulation.

PATH OF CIRCULATING WATERS

The immediate cause of circulation is a difference in pressures in different parts of the ground water, the latter being one great body of water connected by pore spaces of various sizes. A change in pressure at one place is transmitted with great speed for a great distance since very little movement is involved and, therefore, little friction. The movement of water will take place in the direction of least resistance. We have been too accustomed to think of this circulation as lateral (along bedding). Chamberlin pointed out that artesian pressures are related to thickness of overburden and height of ground-water table as well as to the perviousness of overlying rocks, and that all artesian pressures decrease away from the source of intake.[1]

The only reason why water should travel more freely laterally than transversely in a shale is because the particles are arranged with long axes parallel to the bedding and the pores are smaller in transverse direction. But cross-bedding on a minute scale is as common in shales as the more conspicuous cross-bedding of sandstones, and a shingling arrangement of the tiny plates of a shale is as likely to be present. Many shales are so poorly bedded as to show conchoidal fracture in any direction. So the path of least resistance for whatever circulation does take place in a shale is no more likely to follow the bedding strictly than in a sandstone except possibly in some well-laminated shales. A clayey sand may be nearly as impervious as a shale.

Limestones are probably more impervious than shales except that they are more likely to be fractured in a fashion to permit transverse circulation.

[1] T. C. Chamberlin, *Fifth Ann. Rept. of the U. S. Geological Survey*, pp. 134 ff. This is an excellent brief statement of principles involved in artesian-water circulation.

Sandstones are commonly cross-bedded so that transverse circulation is nearly as easy as lateral circulation within the limits of the bed, except that fine and coarse beds may be superimposed. Even cross-beds in sandstones vary in porosity. In general, assortment in sands is more important in determining their permeability than the size of the grains themselves.

Joints provide paths of circulation across bedding planes more perfect than the bedding planes.

Since the circulations that cause the transfer of water from one place to another are very slow, friction is almost negligible. Likewise, transverse circulation across beds of considerable variation in size of pore space is not impeded by friction as it would be in rapid circulation. We may at once prove this by citing the fact that some of the forces acting on the ground water are of enormous magnitude, and yet we never meet enormous pressures in sand lenses entirely surrounded by impervious shales. Since water is by no means incompressible, we should expect to find large bodies of water under pressure commensurate with the weight of overlying rock if transverse circulation did not take place. Nearly all accidents in drilling wells due to high fluid pressures are where gas accompanies the fluid. The close correspondence of fluid pressures actually found and hydrostatic pressures shows that pressures do adjust themselves even through "impervious beds." The practical impossibility of shutting off top water in some oil fields also indicates that transverse circulation is quite feasible. The large amount of water produced year after year in some oil fields is, in the writer's opinion, due to seepage from above and below rather than lateral circulation. If it came through the sand itself, it would soon establish unbroken channels of circulation with edge water and destroy production in the wells.

If we imagine a large body of porous rock saturated with water subject to such great pressure that the pore space would be reduced, a large amount of water would be squeezed out. Escape by transverse circulation might require movement across only a few hundred feet, whereas lateral escape to the outcrop would require movement through hundreds of miles. The sands, even if continuous to the outcrop, contain many cross-beds and patches of fine-pored sand. The overlying beds are normally jointed, and in some places the

joints are open. Is it not certain that a large amount of the water will escape transversely? The water within the shales themselves *must* escape transversely for the most part either up or down to a more pervious bed and then laterally, or else upward to the surface. It is unlikely that the water would actually lift the overlying rock. If it did, faulting would certainly take place and allow the water to escape. Water reaching the sands or more pervious beds would travel (*a*) laterally for a space to the outcrop, or (*b*) by some easier path transversely to a still more pervious bed and thence to the outcrop, or (*c*) partly laterally and partly transversely to the surface. The circulation might even be in diverse directions in different porous layers and the path of least resistance tortuous in the extreme.

We have several proofs of transverse circulation (across beds): (1) no high residual pressures commensurate with weight of overburden, (2) springs along fault lines, (3) vein fillings deposited from water in fractures and faults, (4) solid hydrocarbon in joints on faults, (5) loss of artesian heads not traceable to lower outlet, (6) relation between artesian pressures and depths of overlying waters, (7) long-continued production of water and oil together, and (8) "shale oil" above oil sands.

Transverse circulation is more often upward toward the surface than downward since (*a*) deeper beds are more likely to be offset by faulting; (*b*) they are less porous, being more highly metamorphosed; (*c*) because they outcrop farther away from the source of circulation; and (*d*) they contain fewer open joints. If, however, a relatively open, continuous sand is present beneath a thick body of shale, the water in a considerable part of the shale may find its easiest escape downward and through this sand. It might even cross other less porous or less continuous sands to reach the porous sand. Here we have a reasonable explanation of intermediate waters in oil fields, and of some anomalous occurrences of oil beneath its apparent source.

Wherever transverse circulation occurs in considerable amount we have an adequate explanation for oil and gas accumulation in porous beds if the circulating waters could have carried any oil or gas. The localization of this transverse circulation is probable, as will be shown later.

THE METAMORPHIC CIRCULATION

The metamorphic circulation may be divided into two cycles: (1) due first to simple compacting of the sediments by settling, cohesion, additional overburden, and chemical reorganization; and (2) due to dynamic forces acting horizontally and vertically. The same forces cause folding.

1. METAMORPHIC CIRCULATION DURING SIMPLE COMPACTING

When first deposited, muds contain larger amounts of water than do sandstones. Their specific gravity may be as low as 1.2. The pore space in such a mud may be over 80 per cent and the pore space in a sand as much as 40 per cent.[1] With the increase of overburden, consolidation immediately begins. Who has not observed the little springs of water like tiny mud volcanoes in settling mud? These heterogeneously located paths of transverse escape may persist and be the means of transverse escape through long periods of time. Most muds will settle to a very firm mass, especially those deposited in marine waters. The compacting of the sands also proceeds rapidly to a certain point. This cycle of metamorphic circulation may extend through a whole geologic period and a large part of the connate water be expelled. But sediments do not become well indurated and dense during this cycle, and a considerable part of the water deposited with the sediments still remains. Perhaps 50 per cent of the water in the muds and 25 per cent of that in the sands will be forced out during this cycle. Since this process is long continued and due to constant forces, the circulation will be very slow and largely transverse because the causes localizing upward circulation are not all operating until the next cycle begins.[2]

If any oil is present from the beginning in muds, as seems quite possible under many physiographic conditions, or if any originated during this cycle, this circulation is bound to promote a segregation of the oil in the larger-pored rocks by "screening out" the oil as the water crosses the coarse-textured rocks in its upward course. It is

[1] A rotary mud of 1.6 gravity is much heavier than ordinarily used.

[2] Additional calculations of this kind can be found in F. H. King, "Principles and Conditions of the Movements of Ground Water," *U.S. Geological Survey Nineteenth Annual Report* (1897–98), pp. 77–81. This is a suggestive study of many features of ground-water circulation.

not supposed that this circulation would travel laterally very far, although lateral migration would assume greater proportions with increase in the overburden. Since most of this settling would occur before a thick overburden accumulated, the circulation in deeper beds would be progressively slower.

Any segregation of oil during this cycle would be local and therefore of no commercial importance. Large quantities of gas are formed, as is well known, but it is chiefly marsh gas. It is generally assumed that very little oil is actually present or formed before compression by dynamic activity occurs; at least, it is rather certain no accumulations of commercial importance take place.

We have not spoken of structural features that can arise even during this first cycle of metamorphism. Let us consider a terrane laid down unconformably on older rocks which had been eroded, with old anticlinal structures truncated, and elsewhere "granite ridges" buried. The older sediments below the unconformity would still be susceptible to some shrinkage, those on the axes least of all because oldest and most altered. Thus "reflected anticlinal" structure would result. Eastern Kentucky furnishes some very interesting examples. Powers has discussed "reflected hills,"[1] and his happy phrase is extended to include "reflected anticlines." Anticlinal structures due to reflected hills are caused by greater vertical settling away from the buried hills where the younger strata are thicker. Anticlinal structures of low closure also result from lenses of less compressible sediments overlaid by more compressible strata, or by a greater thickness of the less compressible strata in one place than another. Stratigraphic relations of the foregoing kind cause slight upward bowing of the younger strata with consequent tension and open fissures if the rocks are competent. This will tend to localize the upward circulation and promote lateral migration toward the domes or anticlinal axes, thence upward.

The waters slowly expelled from the buried and truncated structures with their attendant oil and gas will join the waters above the unconformity and the oil will be "screened out." In

[1] Sidney Powers, "Reflected Buried Hills and Their Importance in Petroleum Geology," *Econ. Geol.*, Vol. 17 (1922), pp. 233–59.

some cases this circulation from below might exceed the possibilities of upward circulation in the younger beds, despite their anticlinal attitude, and there would be some dispersal of the circulation away from the structure. But this would be taken care of by the escape of water alone, and the oil would remain near the place of entry into younger beds, or else migrate vertically or laterally to a slight extent.

2. METAMORPHIC CIRCULATION DURING AND AFTER HORIZONTAL COMPRESSION, WHICH PRODUCES FOLDS

Until folding begins we have little or no outcrop of the sands, and very little modification of the metamorphic circulation by artesian circulation except at unconformities. When compression by horizontal forces begins, there may be emergence of part or all of the terrane, and folding and faulting result. A different and more rapid circulation results from the compression. Daly has discussed this cycle[1] emphasizing that synclines are regions of higher pressure and antclines of lower pressure (above the depth of no distortion).

This cycle continues as long as the forces are acting. Large forces are involved. Until erosion bares the porous beds, there is no great tendency for lateral circulation except as transverse circulation itself becomes more localized, and lateral circulation sets up to feed it.

AMOUNT OF WATER EXPELLED DURING METAMORPHIC CIRCULATION

Let us suppose that the rocks comprise three-fourths shale and one-fourth sandstone, and that the pore space at the time of deposition was 50 per cent of the shales and 40 per cent of the sandstones. The pore space by the time the metamorphic circulation has died out may be reduced to 20 per cent in the shales and 15 per cent in the sandstones. The water expelled from the shales during compacting would be 60 per cent of the final volume of the shales and the sandstone would yield approximately 41.6 per cent of the final volume of the sandstone in water. Nearly all this water would travel up or down, but generally upward from the shales toward the sandstones and then follow them toward the outcrop or to some locality where water is seeping transversely across bedding planes toward the surface. The total volume of water thus escaping

[1] *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 56 (1916), pp. 733–81.

through the sandstones would equal 70.4 per cent of the final volume of the shales. This is an enormous quantity of water. It would be two and eight-tenths of the volume of the sandstone, or nearly twenty times the volume of the pore space in the sandstone. This calculation shows that salt-water seeps of considerable size would persist for a long period, and that the freshening of underground waters by artesian circulation could not ordinarily take place except under particularly favorable conditions and then only after the metamorphic circulation is dying out. Even if we grant that most of this water escapes before oil is evolved, the remaining circulation seems fully adequate for migration of the oil through great distances.

All this water was connate water and would retain its original characters except as chemical reaction modified it before reaching the sands. The general similarity of oil-field brines is at least as noteworthy as the differences, and their descent from marine waters hardly questionable. Mills has emphasized further changes due to concentration by evaporation through escaping gases.

ORIGIN AND MIGRATION OF THE OIL

At this point it is best to extend the speculation to the origin of the oil itself and its behavior. White's carbon ratio rule[1] is not dependent on any hypothesis, but seems to be well established where there are sufficient analyses to test it. He offered in explanation of it the hypothesis that where compressive forces acted sufficiently to metamorphose the coal to a carbon ratio of about 65 per cent, the oil and mother-material of oil have undergone such complete metamorphism (katamorphic) that no oil is left and only a modicum of gas remains. The inference is that pressure metamorphism or heat has destroyed the oil and that other evidences of dynamic

[1] David White, *Jour. Wash. Acad.*, Vol. 5, No. 6 (1915), p. 189; "Late Theories Regarding the Origin of Oil," *Geol. Soc. Amer.*, Vol. 28 (1917), pp. 727–34; "Genetic Problems Affecting the Search for New Oil Regions," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 65 (1921), pp. 176–99.

J. S. Fuller, "Carbon Ratios in Carboniferous Coals of Oklahoma and Their Relations to Petroleum," *Econ. Geol.*, Vol. 15 (1920), pp. 225–36.

David B. Reger, "Carbon Ratios in Coals in West Virginia Oil Fields," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 55 (1921), pp. 522–23.

W. Armstrong Price, "Carbon Ratios in Carboniferous Coals of Oklahoma and Their Relations to Petroleum," *Econ. Geol.*, Vol. 15 (1920), pp. 610–12.

metamorphism are therefore equally applicable if they could be standardized. We may note that if oil is once formed it can no longer be subjected to any greater pressure than is present in the ground waters; it becomes a part of the fluid contents of the rock. How high the fluid pressure can rise during dynamic activity we cannot determine, but the writer believes that they are of quite the same order of magnitude as hydrostatic pressures. At any rate, they could not rise above the weight of the rock above, which would be less than three times the hydrostatic pressure, and would not long continue if they reached that maximum. There does not seem to be sufficient difference between the pressure in the ground water where oil has been destroyed and where it still persists, to destroy the oil by pressure metamorphism alone. This argument does not apply to the mother-material, which might be subject to greater pressure. This raises the question, "How old is oil?" and the answer appears to be that oil once evolved is in some manner destroyed within a comparatively brief geologic time, and that it is only the mother-material that can be preserved indefinitely. Where dynamic metamorphism has destroyed all the mother-material, the oil is soon destroyed and no more can evolve. If the oil has not been destroyed by the pressure, it must be a chemical destruction or by heat; in any event, gas would be one of the end-products, fixed carbon remaining in the rocks.

We are led to the conclusion that the oil found in rocks of the same age as those that are barren, but with lower carbon ratios in the coals, is young oil and has not been subjected to the vicissitudes of long-continued contact with ground waters. In California it is said that oils "which have traveled farthest are the heaviest," that is, their volatile constituents have disappeared and they have been more nearly destroyed. The experiments on fractional distillation by passing oil through clays also indicate that oil cannot persist unchanged through far-continued migration, if it migrates in large bodies.

Can oil migrate farther in microscopic globules? How large are the original particles of oil? The mother-material was incorporated in the rock in a disseminated state either as fragments or as coagulations of amorphous material. During compression of the

rocks and rearrangement only minute parts of the mother-material would be subjected to the critical conditions at once, and only minute droplets would form. If the oil originated as oil, it is hard to see how such minute amounts could be detached by circulating waters and floated away through the capillary pores of the shale. If it went through a vapor phase it could easily escape and condense in small globules. It is much easier to account for oil migration if we suppose the droplets were so small that they could be borne freely through the minute pore space of shale without coming in contact with the walls.

LOCALIZATION OF TRANSVERSE CIRCULATION

Let us now examine the reasons for localization of transverse circulation. (1) Any upward convex flexure (whether a closed structure or not) is subject to tension, and open joints and faults of greater or less magnitude develop. This is above the zone of no distortion. The concave or downward flexures are more effectively compressed. This is the immediate cause of localizing the upward escape of water on anticlines, domes, noses, terraces, etc. (2) If fissures and faults do localize the upward circulation, these areas would soon contain waters of slightly higher temperature. An increase in temperature reduces the viscosity of water greatly[1]. That oil fields show higher temperatures has been suggested. Rogers attributed it to oxidation of hydrocarbons. It is here attributed to upward ascension of the fluids also. (3) As soon as significant accumulation of oil begins, gas will also become increasingly abundant. Waters rising from considerable depths would reach a zone of supersaturation and gas would segregate out. Wherever the openings were large enough the escape of this gas would promote the upward circulation both mechanically and by evaporation. (Gas seeps are more abundant than oil seeps, although they only show up in water.) (4) As soon as erosion has truncated the anticlines, the transverse circulation is facilitated by shortening the path of escape. (5) Chemical reaction of the oil itself with surrounding waters or sediments may release some heat, decreasing viscosity of the fluids.

[1] Charles S. Slichter, "Field Measurements of the Rate of Flow of Underground Waters," *U.S. Geological Survey Water-Supply Paper 140* (1905), p. 13.

The writer wishes to emphasize that the metamorphic circulation is caused by strong forces; it is partly transverse and especially likely to be localized in flexures convex upward whether closed or not, and oil carried by the moving water would be "screened out" in coarser-pored rocks. The circulation would rise to a maximum during times of horizontal compression, which are also the times of formation of oil and gas according to several authorities, and would then gradually decline. Successive maxima and minima would arise from several episodes of diastrophism, and the places where circulation upward would be localized might be shifted.

ARTESIAN CIRCULATION

The artesian circulation is better understood and needs little explanation. Whereas the metamorphic circulation is toward the *rim* of the basin and also upward, the artesian circulation is opposite to the metamorphic and *toward* the basin and away from the outcrop. It is caused by forces of less magnitude, of more constant character. It, too, is partly transverse. After erosion has bared the edges of the newly uplifted beds and cut into anticlines, it gathers headway, and a conflict between artesian waters and the slow-moving connate waters begins.

Objection may be made that we have proved too much and insured the leakage of oil rather than its accumulation. But since the pressures causing migration of the fluids can be more easily relieved by the escape of the water which is less viscous than oil, oil will remain behind. If the oil is as fluid as water under certain conditions of pressure and temperature, it will migrate until it meets conditions where it is less mobile than water. Also, if the oil is in small globules, surface tension holds it together and the globule is blocked by a pore that will deform the globule. The paths by which water escapes upward are gradually closed by rock flowage and cementation, or even by solid hydrocarbons or tarlike oils. Furthermore, an accumulation of oil, if more viscous than water, of itself finally clogs the transverse circulation and reduces its importance. Once accumulated, the oil pools tend to form a protective viscous coat or cyst of heavier oils by interaction with oxygen and sulphur compounds; at least heavy asphaltic oils do this.

The metamorphic circulation which is supposed to be the main factor in oil migration reaches a climax of effectiveness during the diastrophic cycle and then declines. By hypothesis the main accumulations are rather far removed from the source of artesian head where artesian circulation is fading out and stagnating against the bulwark of heavier salt waters.

ZONE OF CONFLICT BETWEEN CIRCULATING METEORIC WATERS AND CONNATE WATERS

The battle ground between artesian and metamorphic circulation would fluctuate more or less back and forth over a zone in which the waters seep slowly toward the surface across the strata. Here is another tendency localizing transverse circulation, and it is to be noticed that this zone of conflict, especially the *basinward side*, is the most favorable place for the accumulation of oil. We cannot say just where the boundaries of the zone will be, except that they will lie some distance away from the rims of the basins and will probably be about where the "basinward" folds are located. The battle ground would shift toward the outcrop during periods of folding, and during periods of quiescence artesian circulation would gain dominance and extend its field of operations. There would be some interfingering of these circulations, and the deeper beds would be less easily invaded by artesian waters since outlets are not so abundant and upward escape of artesian heads immensely more difficult. Can this be the reason why deeper oil sands are more likely to prove productive close to the intake edge of artesian basins than shallow sands?

Every consideration points toward artesian circulation being the natural enemy of oil instead of an agency of accumulation as some would have it. The association of brines and oil, the barrenness of "mountainward" structures, and the changes caused in oils by surface waters all prove it.[1]

This fluctuating zone of conflict will explain some things. It accounts for less important accumulation of oil near the rims of

[1] C. H. Wegemann, in an unpublished paper read before the American Association of Petroleum Geologists at Shreveport, concluded that where artesian (fresh) waters were found low down on structures the crests are not likely to contain oil.

basins, while greater accumulations are found toward the basins. It explains fresh waters associated with oil and waters of different composition or temperatures. In the Kern River field, California, we have a large accumulation of oil associated almost entirely with fresh water. Everything indicates that the oil migrated from the basinward side, yet the waters are fresh. It must have been collected there by salt waters circulating under considerable pressure. As the metamorphic circulation died out, artesian water replaced the salt water but was altogether incompetent to shift the oil itself.

The presence of gas in structures toward the edge of the basin with little or no oil is also understandable, since gas is more mobile than the oil, which would lag behind and be intercepted by the first structures. There is no reason why gas should accumulate as long as the water or oil is not saturated with dissolved gas. Water migrating toward the margin of deep basins and also upward would lose the oil in closed structures or other traps, and carry gas farther until close enough to the surface to become saturated and yield free gas. Gas would occur above the oil and in folds closer to the edge of the basin. Transverse circulation would carry gas up higher in closed structures and release it in sands above the oil.

If gas is a product of the destruction of oil, some gas fields may represent the last stages of destruction of an oil field.

PERIODIC MOVEMENTS

Slichter commented on the speed with which changes in hydrostatic pressures are communicated.[1] Compression waves travel with great velocity since very small movements, and therefore little friction, are involved. Compression waves may be caused by earthquake shocks, variation in barometric pressure, by tidal action both in the solid earth and in the seas, and possibly by electric conditions also. Somatic waves (compression waves in water) have lately been made use of to transmit power in rock drills which are commercially successful, and in sounding devices. Someone has argued that even minute motions of water in capillary pores would greatly facilitate the segregating of oil, water, and gas. Of these periodic

[1] C. S. Slichter, "Field Measurements of the Rate of Movement of Underground Waters," *U. S. Geological Survey Water-Supply Paper 140* (1905), p. 71.

oscillations tidal action in the solid earth appears the most effective, as Shaw has suggested. If the ground-water movements are slow, movement may only take place when assisted by compression waves with stagnation during the opposite phase. The water and oil would move in jerks. The writer once had the pleasure of observing some experiments in which vibrations of minute amplitude were set up in water by means of alternating electric currents derived from a Poulsen arc affecting a quartz crystal between electrodes. It was a piezo-electric effect. The vibrations were so small that no motion of the water could be detected by the eye, but immediately air in solution in the water separated out in tiny bubbles and these bubbles arranged themselves in layers, apparently at nodes of vibration in some manner. These bubbles could be seen dancing up and down and did not rise through the water. Since crystals with piezo-electric properties are found in all sediments, it is possible that even this sort of thing could be of some importance.

CAPILLARY CIRCULATION

Since the pores of shale are all of capillary size, capillary phenomena must be of great importance. So far as this difficult subject has yet been elucidated, it appears that the chief importance of capillary action is to hold oil in the larger pores, once the globules or masses reach sufficient size to fill the capillary. Whether or not it can actually cause migration of oil except for very small distances appears doubtful. It seems better as an anchor than a sail. It has been appealed to as the factor sealing the high "rock pressures" occasionally met. Regarding these high pressures we need more exact information. It is very rare, indeed, to find gas pressures that cannot be held down by very thin rotary mud if the hole is kept full and the mud in circulation. No doubt great pressure could be caused in a gas body underground if it was entirely surrounded by pores none of which were above capillary size. It has occurred to the writer that high, closed pressure in wells may be of such origin, a gas pocket having formed near the well when allowed to flow; when the well is closed, capillarity compresses the pocket of gas.

SUMMARY

Various causes of ground-water movements are examined deductively, especially (1) circulation due to metamorphism of the rocks and (2) artesian circulation. The metamorphic circulation, being caused by compacting and folding of rocks containing connate waters, is of greater power, and the waters squeezed out circulate toward the margins of structural basins and also upward across the strata. The upward circulation during metamorphism is at first diffused, but becomes more and more localized, especially after diastrophism has gone far enough to form folds. The artesian circulation is due to percolation of meteoric waters through porous beds toward structurally and topographically lower positions, this circulation gradually fading out, due to upward seepage.

Transverse circulation, which is rather uniformly distributed during the early stages of metamorphic circulation, is increasingly localized. As upward flexures of the rocks are formed (closed or not), tension joints and faults and erosion on top of the flexures facilitate upward circulation in certain areas. At the same time, downward flexures are more effectively compressed. Wherever transverse circulation tends to predominate, the ground waters become warmer in those places and a decrease in viscosity due to this factor allows much more rapid escape of transverse circulation. The oil tends to remain behind in larger-pored rocks. Reaction of hydrocarbons with constituents of ground waters may be an additional source of heat. The escape of dissolved gas aids the upward migration of water. All the factors are therefore cumulative and promote localization of transverse migration until more or less self-destructive by the sealing and cementing shut of joints and faults or the accumulation of a large body of oil more viscous than water. When the dynamic activity dies out, the process comes to an end or proceeds very slowly.

The argument also indicates the presence of a "zone of conflict" between the two circulations which are in opposite direction in so far as they are not both upward toward the surface. The artesian circulation is supposed to be inimical to oil, while the metamorphic circulation is the real agency of accumulation, artesian circulation

being mainly influential in establishing the "zone of conflict" where waters rise upward.

The interaction of metamorphic circulation and artesian circulation in the manner described and the localization of transverse circulation are thought to explain the locations of regions of oil accumulation, the relation of gas and oil fields to each other, and also the presence of gas sands above oil sands, as well as intermediate waters. The main accumulations are to be expected stratigraphically above the original source of the oil but some accumulations below are probable.

Other causes of ground-water movement which are of more aid in segregation of oil, gas, and water than in migration are cited but not discussed at length.

Tentative conclusions regarding the time oil will persist are stated, the carbon ratio rule being construed as an argument for a comparatively recent origin of oil, only the mother-material being able to persist for a long geologic time.

The main contention is that slow seepage of water across bedding planes is equally important with lateral circulation in causing accumulation, and this transverse circulation will tend to be confined to certain structural locations.

TEXTURE OF OIL SANDS WITH RELATIONS TO THE PRODUCTION OF OIL[1]

A. F. MELCHER
U. S. Geological Survey, Washington, D.C.

SCOPE OF THE INVESTIGATION

In an investigation of oil and gas production a study of the physical properties of the sands that serve as reservoirs, as well as the physical properties of oil and gas, is very important. Physical factors of oil sands that should be studied are pore space; size and shape of grains; size and shape of pores of the sand; permeability, or rate of flow of oil through the sand, under definite drops in pressure between the entrance face and exit face of the sample; absorption, or the quantity of oil which a unit volume of the sand will absorb under physical conditions similar to those that exist in nature; the degree of saturation of oil sands with oil; retentivity, or the capacity of an oil sand to retain its oil under given conditions; and relation between thickness and extent of the producing part of the sand and oil content and yield. Temperature, specific gravity, and viscosity of the oil are important, and relations of oil, gas, and water, and influence of capillarity should be considered. To study effectively relations of oil, gas, and water and influence of capillarity some pool should be selected and changes in relative positions of the oil, gas, and water should be observed from the beginning of development until the pool is abandoned, in order to ascertain the relative progress of water encroachment in various textures of sands and the influence of structural conditions. Not only is it important to study these natural factors in the production of oil and gas, but it is also important to take into consideration the artificial factors, especially methods of management of wells after they are drilled in. Such artificial factors which should be

[1] Published by permission of the director, U. S. Geological Survey. Read by title before the Association at the Shreveport meeting, Louisiana. Manuscript received by the Editor, April 22, 1924.

considered are diameter of hole through pay sand, influence of offset wells and offset leases, spacing of wells for most efficient recovery, dates of completion of wells, which would influence the production of the well or tract considered, casing troubles, size and position of casing at time of shot, number of times well is shot, size of shots, depth to top and bottom of shot, dates of shots, production of wells before and after shots, and influence of shots on offset wells, as well as on wells shot. In such an investigation, the observer should study field conditions, collect field data, combine laboratory and field work, develop methods and make careful quantitative measurements upon as many of these physical properties as possible, and ascertain the relations existing directly or indirectly between these physical factors and the normal and ultimate yield of oil.

ACKNOWLEDGMENTS

The original inspiration of this work came from the Petroleum Club of the United States Geological Survey. K. C. Heald and David White are more specifically responsible, as their support made the work possible, and they have continued with interest and helpful suggestions throughout the entire investigation. The first field trip was arranged by E. W. Shaw. C. E. Van Orstrand read the entire paper and gave helpful suggestions. Marvin A. Shoultes assisted in checking the computations and in making the drawings.

The officials of the Bureau of Mines, the geologists, field superintendents, drillers, and other field men of oil companies in the fields visited have given generous co-operation, without which it would have been impossible to have obtained materials for this investigation. Among the consulting geologists thanks are due to M. J. Munn and J. O. Lewis, Tulsa, Oklahoma; David Donoghue, Houston, Texas; and Roswell H. Johnson, Pittsburgh, Pennsylvania. Others who collaborated in parts of the work are mentioned later in connection with special investigations.

PREVIOUS WORK

Although two sets of apparatus have been designed and built and preliminary experiments have been made on permeability and

absorption of oil and gas sands, this paper, which is the second progress report,[1] deals mainly with pore space and size of grain of oil sands, with the variations of these properties in different fields of the United States, and with their variations in a particular field, especially in so far as such variations may affect the production of oil.

Considerable work has been done on porosity of building stones, soils, and ceramic materials, but very little work has been published in English on porosity of oil and gas sands, other than the work of the writer.

J. F. Carll[2] made, "in a crude way," experiments on a number of pieces of the "third sandstone" taken from oil-wells at Tidioute, Pennsylvania. His conclusion was that the "third sandstone" was capable of holding from 7 to 10 per cent of its own volume of oil. These experiments were made on specimens of rock whose pores were more or less clogged with residuum from oil that had been held in it, and without the specimens being charged under pressure.

A. W. Lauer[3] emphasizes the importance of openings in the sands resulting from folding, cracks, crevices, joints, solution cavities, and other openings, induced after the sedimentary formations had been deposited. A number of other writers have made comparison statements or estimates of the porosity of oil sands.

A. B. Thompson[4] states that compact sands may absorb from 10 to 20 per cent of their bulk, and loose sands from 25 to 50 per cent of their volume with petroleum.

Sir Boverton Redwood writes:

> As regards the capacity of the various oil strata to serve as an oil reservoir, experiments performed on the rock itself have shown that an oil-bearing pebble-rock may contain one-tenth or even one-eighth of its bulk of oil, while the pores of the rock would permit the ready removal of the largest supplies ever obtained, without the necessity for the channels, which were at one time supposed to

[1] The first progress report is "Determination of Pore Space of Oil and Gas Sands," by the writer, *Bull. Amer. Inst. Min. and Metal. Eng.* No. 160 (April, 1920), Sec. 5, pp. 1–22.

[2] "The Geology of the Oil Regions of Warren, Venango, Clarion, and Billings Counties, Pennsylvania," *Second Geol. Surv.*, Vol. 1[3] (1880), p. 251.

[3] "The Petrology of Reservoir Rocks and Its Influence on the Accumulation of Petroleum," *Econ. Geol.*, Vol. 12, No. 5 (August, 1917), pp. 435–72.

[4] *The Oil Fields of Russia* (London, 1904), p. 45.

exist. The dolomitized portion of the Trenton limestone has been found to possess about the same capacity. The oil sand of Baku, Russia, is estimated to contain about one-fifth of its volume of oil.[1]

Dorsey Hager states:

> Voids in the various kinds of strata vary considerably. Sands may contain from 15 to 35 per cent voids; sandstones, 5 to 15 per cent voids; conglomerates may contain as high as 30 per cent voids; shales, from 2 to 10 per cent; and some dolomitic limestones are reported to contain as high as 35 per cent voids. The percentages are so variable that one must not take the material in one field to be a criterion or measure of material in other fields.[2]

Roswell H. Johnson and L. G. Huntley in their book[3] refer to Bell's estimate of the oil reserve of California in which 10 per cent of the oil is considered recoverable, and state that the effective porosity of oil and gas sands is so important that the United States Geological Survey or United States Bureau of Mines should give some accurate figures.

C. W. Washburne[4] uses a porosity factor of 15 per cent for the average oil sand.

J. O. Lewis[5] and W. H. Emmons[6] have made collections of data on porosity of building and ornamental stones, of sands, and of oil sands.[7]

A few of the many publications in English which give either data on porosity of building and ornamental stones, and water-producing beds, or both data on pore space and methods of determination of porosity of these stones, are listed below:

E. R. Buckley[8] not only collected data and made determinations on absorption of building stones for water, but made a distinct

[1] *A Treatise on Petroleum*, Vol. 1 (4th rev. ed., 1922), p. 162.

[2] *Practical Oil Geology* (3rd rev. ed., 1918), p. 9. Tulsa, Oklahoma.

[3] *Oil and Gas Production* (1916), p. 34.

[4] "Estimation of Oil Reserves," *Bull. Amer. Inst. Min. Eng.*, No. 98 (February, 1915), pp. 469–71.

[5] "Methods for Increasing the Recovery from Oil-Sands," *U. S. Bureau of Mines Bull. 148* (1917), pp. 16–18; and Carl H. Beal and J. O. Lewis, "Some Principles Governing the Production of Oil Wells," *ibid., Bull. 194* (1921), pp. 5 and 6.

[6] *Geology of Petroleum* (1921), pp. 59–64. Minneapolis, Minn.: University of Minnesota.

[7] The porosity data given in the *U. S. Geol. Surv. Bulletins 629* and *670* were determined by the writer.

[8] "Building and Ornamental Stones of Wisconsin," *Wis. Geol. and Nat. Hist. Surv. Bull. 4*, pp. 64–69 and 414.

advance step in developing a method for finding the porosity of these stones. D. W. Kessler[1] describes a method for finding porosity of building stones, and gives the results of a number of determinations. G. P. Merrill[2] gives the ratio of water absorption of a number of building stones of the northeastern states. J. A. Bownocker[3] cites six tests of the porosity of Berea grit, which gave results from 15.9 to 17.8 per cent. The determinations were made by Professor D. J. Demorest, of Ohio State University, by the absorption of water method and comparison of the apparent specific gravity of a fragment of the stone with the specific gravity of its individual grains. W. A. Parks[4] gives tables on pore space and ratio of absorption of limestones and sandstones. O. E. Meinzer[5] gives a comprehensive discussion on conditions controlling porosity and methods of determination of pore space for water-producing beds. Mr. Meinzer also gives data on the percentage of pore space of various rocks, sands, and soils.

RESERVOIR ROCKS FOR OIL

Though the writer realizes the importance of source or origin of the oil sand[6] and the influence that manner of deposition of sediments must have on pore space, sizing, and distribution of sizes and shapes of grains in oil sands, only a very general discussion of these factors will be given here. Eroded shale would not be promising material for the reservoir rock for oil. Weathered limestone, on the other hand, would furnish chert and flint, which under some conditions would make good material for the reservoir rock. If the limestone becomes cavernous, as in some of the Mexican fields, or forms nodules, or becomes granular, or crystallizes with pores

[1] "Physical and Chemical Tests on the Commercial Marbles of the United States," *Tech. Papers of the U. S. Bureau of Standards*, No. 123 (1919), pp. 17–22, 49.

[2] *Stones for Building and Decoration* (1903), pp. 498–508.

[3] "Building Stones of Ohio," *Ohio State Geol. Surv. Bull. 18* (4th series, 1915), p. 77.

[4] "Building and Ornamental Stones of Canada," *Canada Dept. of Mines, Mines Branch*, Vol. 1 (1912), pp. 349–50; also tables are given in other volumes on building stones from Volumes 2–5, inclusive, of this Department, by the same author.

[5] "The Occurrence of Ground Water in the United States," *U. S. Geol. Surv. Water-Supply Paper 489* (1923), pp. 2–17.

[6] "Oil sand" is used in this paper with the broadest meaning, including any formation which acts as a reservoir rock for oil. However, most of the work has been done on sands or sandstones, made up of individual grains.

between the crystals, or is fossiliferous with openings between the fossils, as in some cases in the Deaner field, Okfuskee County, Oklahoma, or is altered to dolomite with interlocking crystals, as in the Lima-Indiana field, it forms an excellent oil-containing rock. However, the most general reservoir rocks for oil are sandstones or oil sands which are derived from eroded igneous rocks high in percentage of quartz. The eroded material from these rocks, when properly sorted and laid down under conditions that tend to form beds of high porosity, makes excellent oil-containing formations.

Openings in rocks have been very arbitrarily classified by Alfred Daniell[1] and C. R. Van Hise[2] into three groups—supercapillary, capillary, and subcapillary—by giving values to ranges of different sizes depending on the action of water in them. Supercapillary openings are considered to be those with tubes greater than 0.5 mm. in diameter, or sheet openings more than 0.25 mm. wide. These openings are assumed to be sufficiently large to obey the ordinary laws of hydrostatics. Capillary openings are assumed to be tubes less than 0.5 mm. and greater than 0.0002 mm. in diameter, or sheet openings between 0.25 mm. and 0.0001 mm. wide. In these openings water does not obey the ordinary laws of hydrostatics, but is affected by capillarity. Subcapillary openings with circular shapes are supposed to have diameters less than 0.0002 mm. and sheet openings less than 0.0001 mm. wide. These values will be modified in the future, for measurements by different investigators vary greatly. It must be recognized that the properties of capillary and subcapillary openings will be affected by the composition, temperature, and viscosity of the liquid in them as well as by the composition and structure of the walls inclosing them.

FACTORS INFLUENCING SIZE OF OPENINGS AND PERCENTAGE OF PORE SPACE IN ROCKS

Some of the factors determining size of openings and percentage of porosity in rocks where oil accumulates are the origin of the openings, distribution of sizes of grains, shapes of grains, the way the individual grains are laid down, and cementation.

[1] *A Text-Book of the Principles of Physics* (1895), p. 315.

[2] "A Treatise on Metamorphism," *U. S. Geol. Surv. Mono. No. 47* (1904), p. 135.

W. H. Emmons[1] has classified voids in rocks, with respect to their origin, into primary and secondary openings. The primary openings are subdivided into "intergranular spaces," openings in "bedding planes, vesicular spaces, openings in pumice, miarolitic cavities, and submicroscopic spaces." The secondary openings are subdivided into "openings formed by solution, shrinkage cracks due to dehydration, cooling or loss of fluids, openings due to force of crystallization, ... to the thrust of solutions, ... and to the greater earth stresses."

Oil and natural gas have accumulated mainly in intergranular spaces, openings in bedding planes, and secondary openings. They are seldom found in large quantities in the other primary openings, such as openings in igneous rocks. Intergranular spaces vary from very small submicroscopic openings, in rocks made up of very fine sand and shale, to large pores in rocks made up of either coarse sands or gravel.

In cavernous limestones, which act as reservoirs for oil, openings are usually rather rounded and large. Crystallization gives openings of various forms and sizes, depending largely upon habit and size of crystals, and the way they are placed in respect to one another.

The distribution of sizes of grains of a granular rock, where its grains approximate spheres in shape, is important in determining the size of pores and the percentage of pore space. If the grains of sand are well rounded and uniform in size, the percentage of pore space will vary from about 26 per cent to less than 48 per cent[2] for its maximum.

In most oil sands of Central and Eastern United States, the shapes of grains do not approximate spheres, and they are not uniform in size, but have various shapes and vary in size, so that very important factors, in determining percentage of pore space, are the way in which the grains are laid down, and the quantity and mode of occurrence of cementing material between the grains, as well as shapes and distribution of sizes of grain. In an extreme case where

[1] *Geology of Petroleum* (1921), p. 42.

[2] C. S. Slichter, "Theoretical Investigations of the Motion of Ground Waters," *U. S. Geol. Surv., Nineteenth Annual Rept.*, Part 2 (1899), pp. 309–10.

the grains of a granular rock have shapes which approximate parallelopipeds, with edges and corners only slightly rounded, the grains could be laid down so that there would be either a very large or very small percentage of pore space.

FIELD EXAMINATION AND COLLECTION OF SAMPLES OF OIL AND GAS SANDS

Methods of field examination and collection of oil- and gas-sand samples vary a great deal, depending upon such factors as location of the field, geological structure of producing formation, operating conditions—including methods of drilling, shooting, and cleaning out wells, the kind of rock and texture of the pay sand, and water-sand relations.

OUTCROP SAMPLES

In some of the oil fields in Wyoming and California the outcrops of the oil-producing formation are sometimes only a few hundred feet from the producing field. A good example of outcrops of the oil measures less than a mile distant from some of the producing wells is the Osage oil field, Wyoming. The nearness of the outcrop depends upon the geologic structure and the topography. Series of chunk samples should be taken from top to bottom of these outcrops in several different places, where weathering has not materially changed its texture.

The laboratory technician can co-operate to advantage with the geologist in selecting locations for collecting representative samples of the different texture types of the outcrop rock, as he can quickly recognize changes in texture, such as sudden variations in size of grains, in quantity of cementing material, in shapes of grains, in hardness of the rock, and in the manner in which it breaks from either impact or crushing, or both. It is very important that the samples shall not be appreciably changed in texture by weathering, so they should be collected when possible from excavations, such as railroad and road cuts, tunnels, or shafts. Samples gathered from outcrops of the pay sand which are many miles from the producing field have some value, as examination of these samples not only gives general information on texture but furnishes evidence of what may be expected of the texture of the formation between the outcrop

and its producing area, especially if any physical properties of the formation are persistent for some distance along the outcrops. Measurements, or at least close estimates, should be made both along the strike and at right angles to the dip of the rock for the persistence of the texture type of any sample gathered. The presence in the outcrop rock of cracks, crevices, joints, solution cavities, and other openings not caused by weathering or interstitial spaces should be noted with the approximate size and frequency of these openings. If possible, these openings should be carefully differentiated from openings caused by alteration of rock at the surface.

WATER-SAND OUTCROPS

The oil-yielding formation in one area very often yields water in another, and in the same area one part of a formation will yield oil while the other part will yield water. As it is not possible to differentiate between the two types of sand at their outcrops, chunk samples of the water sand from outcrops should be collected for general scientific information on accumulation and segregation of oil and water, and the texture of these samples will often give useful knowledge in locating water troubles in the neighboring producing area. The general method for collecting samples at outcrops of oil sands should be applied to collecting samples from outcrops of water formation.

FIELD EXAMINATION AND COLLECTION OF SAMPLES FROM WELLS

The method of collection of samples from wells depends very largely upon factors such as methods of drilling, of shooting, and of cleaning out the wells. The texture and kind of producing formation are quite important as well as location and the geologic structure.

The two general systems of drilling in the United States are the rotary-drill and churn-drill systems. Diamond-core drilling is becoming more popular on account of the scientific interest and practical importance of the study of these cores from the different rock formations in relation to production of oil. By this method practically a continuous core of the oil formation as well as any other geologic measures can be obtained. The collection of the samples for texture study, when this method is used, is very much

simplified, as a careful examination of the cores permits selecting of samples that are representative of the different texture types and noting the distance over which each texture type extends. The examination should extend from top to bottom of the producing bed. The cores also show very definitely any partings or breaks that may occur in any formation such as sand streaks in shale or shaly partings in sand.

It is practically impossible to obtain fragment samples of producing formations from the rotary-drilling system unless the core barrel is used. When the core barrel is employed almost continuous cores of the rock formation can be obtained.

Nearly all of the oil and gas wells in the Mid-Continent, Appalachian, Lima-Indiana, and Rocky Mountain fields are drilled by the churn-drill system. Most of the oil-sand samples that have been collected have come from wells drilled by this system.

After the churn drill has pounded a few feet down through the rock the bailer is run to bail out the finely pounded-up material. This fine, pounded-up rock or slush should be carefully searched for fragments which show the texture of the formation. The separation of these fragments is easily accomplished by emptying the contents of the bailer into a barrel, a large tub, or other receptacle of sufficient capacity to hold the contents of the bailer and washing out the finer material. Special washing machines could easily be designed for separating the larger fragments from the finer material by making use of the two processes of washing and screening the slush emptied from the bailer or from the sand pump, which is sometimes used. A bucket is generally used by the driller for catching the material from the bailer, but this receptacle is so small that often the fragments are washed out into the slush pond before the bailer can be raised and its valve closed. The sand pump is a great deal more useful in obtaining fragments of oil- or gas-producing formations than the bailer, as the opening in the bottom of the sand pump is larger and there is no valve stem extending several inches below the pump to obstruct the entrance of fragments into its containing chamber. The absence of the valve stem below the sand pump allows it to approach closer to the bottom of the well than the containing chamber of the bailer.

In the churn drill method the chances of obtaining fragment samples of rock formation are increased if the driller keeps his drills well sharpened and dressed when samples are sought. In producing formations where it is difficult to procure chunk samples, as is the case in some limestones, fragments can sometimes be obtained by letting a well-dressed and sharpened bit strike the rock several hard blows and then using the bailer or preferably the sand pump to bring the pieces to the surface.

Fragments are also obtained by using some of the various fishing tools, such as the grab basket. The Keystone Driller Company, Beaver Falls, Pennsylvania, manufactures a bit designed to take cores with percussion drilling outfits. If the lower end of a piece of wrought-iron pipe or small diameter casing is saw toothed and these teeth bent slightly in toward the center of the opening of the pipe, fragments are sometimes caught by these teeth when they are struck into the pay sand. R. E. Collom[1] describes several methods and devices which can be used by the cable and rotary-drill system, for obtaining chunk samples or cores of oil sands. However, all of these special methods take up time, which often is very important to the operators.

When a well is being drilled in, fragments should be procured by washing the drill cuttings which are bailed out from each screw. These fragments should be examined, and samples should be collected from every screw from the top of the cap rock to the bottom of the producing sand, so that the samples will show the various types of texture for the producing sand of the well. Both the location of the well with reference to the geologic structure and the angle of dip of the strata should be considered when the samples are collected. The selection of representative fragments of each screw involves a comparison of the texture of the fragments of the last screw with the texture of the fragments of the previous screws which extend to the top of the producing formation. The comparative selection of the fragments is necessary on account of the fact that often samples in the last screw are cavings from the producing sand above. Changes in texture can usually be seen by

[1] "Prospecting and Testing for Oil and Gas," *U. S. Bureau of Mines, Bull. 201* (1922), pp. 114–23.

field examination, but several fragments of the sand should be taken from each screw, so that further examination and tests can be made in the laboratory. The fragments should be studied both while they are wet and after they are dried. Wet chunk samples usually show partings more easily, while dried cuttings will generally show fine sand, which is mixed with shale, more readily. A hand lens is very useful for field examination of the texture of samples from oil-producing formations.

Sometimes chunks of the producing sand are obtained when the well is shot or are bailed out in cleaning the well after the shot. The sand pump is especially efficient in procuring large pieces of the rock after the well is shot. These larger pieces of rock should be compared with the drill cuttings to select the representative types, whenever it is possible to do so. Mr. R. Van A. Mills, of the United States Internal Revenue Bureau, has also suggested the method of comparison of drill cuttings with chunks.

Too much emphasis can hardly be placed upon the care with which the field examination and selection of representative samples of the different texture types of a producing formation should be made. Otherwise the laboratory examination and tests will be of little value.

METHODS FOR THE DETERMINATION OF PORE SPACE

There are three principal methods for the determination of pore space of porous substances. Probably the oldest is the absorption method, which depends on the absorption of both liquids and gases by a substance. In case a gas is used, the gas is allowed to expand in a measured volume and the drop in pressure is noted. A second method is the comparison of the apparent specific gravity of a fragment of the substance with the true specific gravity of the solid particles of the substance. The third method is the comparison of the volume of the fragment with the volume of its solid particles.

DETERMINATION OF PORE SPACE BY METHOD OF FINDING THE RATIO OF ABSORPTION

The method of finding the ratio of absorption has often been used for finding the percentage of pore space of building and ornamental stones. The sample to be tested is heated at a temperature

of 100° C. to drive off the moisture, cooled, weighed, and then slowly immersed in distilled water. After bubbles cease to be given off, the specimen is removed from the water, the surface is quickly dried with bibulous paper, and again weighed. The difference between the two weighings gives the increase in weight due to the absorption of water. The difference divided by the weight of the dry stone is called the porosity, or ratio of absorption.

Three errors are apparent in this method of determination of porosity, according to E. R. Buckley.[1] All the interstitial water is not completely expelled at 100° C. The sample of building stone must be heated to 110° C. The specimens are not completely saturated simply by immersion in distilled water until bubbling ceases. It follows that the porosity is not obtained by dividing the weight of the dry specimens by the increased weight due to absorption.

BUCKLEY'S METHOD OF DETERMINING POROSITY OF BUILDING STONES

E. R. Buckley,[2] at the laboratory of the University of Wisconsin, devised his method from the principle that the true specific gravity of a rock can only be obtained by weighing the samples in air at a definite temperature, after all the interstitial water has been expelled; then weighing them, completely saturated with water, in water; and finally by dividing the weight in air by the difference. He recognized that the foregoing ideal conditions are difficult to obtain, but by sufficient care he thought that these conditions can be nearly attained.

The method used by Buckley in obtaining the porosity was to multiply the difference between the saturated and dry weights of the sample by the specific gravity of the stone. This product was added to the dry weight, and this sum was divided into the difference between the saturated weight and dry weight multiplied by the specific gravity. The quotient gave the porosity of the specimen.

While Buckley's method of determining porosity for building stones is a decided improvement over the method of finding porosity

[1] "Building and Ornamental Stones," *Wis. Geol. and Nat. Hist. Surv., Bull. 4* (1898), pp. 64–69.

[2] *Op. cit.*

by method of ratio of absorption, his method still depends upon expelling all water and other foreign material from the interstices of the fragment sample as well as upon obtaining complete saturation of the fragment of stone. These two processes would be very difficult if not impossible when applied to oil sands, especially where oil-sand samples are friable and interstices still hold residual oil. By absorption tests on building stones Hirschwald has shown that the method of gradual immersion in boiling water under a vacuum seldom gives complete saturation, but that the samples must also be placed under a pressure of from 50 to 150 atmospheres for complete saturation.

There is a series of seven articles on porosity of ceramic materials by E. W. Washburn,[1] E. W. Washburn and F. F. Footitt,[2] and E. W. Washburn and E. N. Bunting.[3] These articles discuss porosity and methods for determining porosity especially of ceramic materials comprehensively. The two main methods developed in these articles are the expansion of a gas method and the McLeod-Gauge method. These two methods, which depend upon the absorption of gases and which are a decided improvement over liquid absorption methods for ceramic materials due to the low viscosity and expansibility of gases, are not applicable to the determination of porosity of oil sands, as it would be necessary to clean the pores of the fragment sample of all foreign material. This process would be very difficult, if not impossible, especially in case of the very friable samples without injury to them. These writers also agree that liquid-absorption methods for the determination of

[1] "Porosity I. Purpose of the Investigation," "II. Porosity and the Mechanism of Absorption," *Jour. Amer. Ceramic Soc.*, Vol. 4, No. 11 (November, 1921), pp. 916–22.

[2] "Porosity III. Water as an Absorption Liquid," *ibid.*, No. 12 (December, 1921), pp. 961–82.

[3] "Porosity IV. The Use of Petroleum Products as Absorption Liquids," *ibid.*, pp. 983–89.

"Porosity V. Recommended Procedures for Determining Porosity by Methods of Absorption," *ibid.*, Vol. 5, No. 1 (January, 1922), pp. 48–56.

"Porosity VI. Determination of Porosity by the Method of Gas Expansion," *ibid.*, No. 2 (February, 1922), pp. 112–29.

"Porosity VII. The Determination of Porosity of Highly Vitrified Bodies," *ibid.*, No. 8 (August, 1922), pp. 527–37.

porosity are unreliable and would seldom give complete saturation unless very long periods of soaking or high pressures are used.

METHOD OF COMPARISON OF SPECIFIC GRAVITIES FOR THE DETERMINATION OF PORE SPACE

D. W. Kessler[1] uses the method which compares the specific gravity of a fragment of the stone with the specific gravity of its solid particles to determine the percentage of pore space of building and ornamental stones.

The apparent specific gravity was found from the formula

$$G=\frac{W_1}{W_2-W_3},$$

in which W_1 = the dry weight of the cube, W_2 = the weight of the cube after soaking in water but dried on the surface with a towel, and W_3 = the weight of the soaked cube suspended in water.

The true specific gravity of the powdered stone was determined by the Le Chatelier flask.

The percentage of pore space was found from the equation

$$P=\frac{100\,(t-a)}{t},$$

in which t is the specific gravity of the powdered stone and a is the apparent specific gravity of the stone.

Kessler's method, which was developed for building stones, is not applicable to the determination of porosity of most oil-sand samples, as the apparent specific gravity depends upon expelling all foreign material from the interstices of the fragment sample of rock. Any substances left in the pores would change the apparent specific gravity. It would be very difficult to expel in a reasonable time all the oil from the pores of hard-chunk samples and prevent disintegration of the friable ones.

Arthur Holmes[2] in his book, *Petrographic Methods and Applications*, Part I, gives several methods for finding porosity. His methods depend either upon a comparison of the apparent specific

[1] "Physical and Chemical Tests on the Commercial Marbles of the United States," *U. S. Bureau of Standards Technol. Paper No. 123* (1919), pp. 17–22.

[2] *Op. cit.* (London, 1921), pp. 43–52.

gravity with true specific gravity or upon the saturation of the rock with a liquid. In most cases these methods would not be applicable for determination of porosity of oil sands.

DETERMINING PORE SPACE OF OIL AND GAS SANDS

Only slight modifications in the method previously described by the author[1] are given here. The method selected for determining the pore space of oil and gas sands is based on the principle that the volume of the fragment of the sand minus the volume of its individual grains equals the volume of the pore space. The volume of the pore space divided by the volume of the fragment gives the percentage of pore space by volume. The volume of a fragment of sand is chosen because it is a constant factor. Density and weight of a fragment of sand are not constant unless all substances are removed from its pore space, but will vary with the quantity and kind of material in the pores of the stone.

There are several other methods for determining the volume of the fragment besides weighing the sample in water after it has been dipped in paraffin. These methods consist in using some form of the pycnometer or the volumenometer. The following writers have described volumenometers for finding the volume of substances: L. Zehnder,[2] A. Lo Surdo,[3] Julius Hirschwald,[4] and E. W. Washburn and E. N. Bunting.[5] These writers used mercury, water, or gas for the measuring substance. Washburn and Bunting also describe a special form of pycnometer for finding bulk volume. The John Johnson and L. H. Adams[6] pycnometer could be modified by greatly increasing the internal diameter of the neck of the pycnometer and using it as a volumenometer for finding bulk volume.

[1] "Determination of Pore Space of Oil and Gas Sands," *Bull. Amer. Inst. Min. and Metal. Eng.*, No. 160, Sec. 5 (1920), pp. 2–9.

[2] "Ein Volumometer für kleine Substanzmengen," *Annalen der Physik*, Vol. 10 (1903), pp. 40–71, also "Ein Volumometer für grosse Temperaturintervalle," *ibid.*, Vol. 15 (1904), pp. 328–43.

[3] "New Volumenometer," *Nuovo Cimento*, Vol. 12 (July and August, 1906), pp. 41–47; also *Science Abstracts*, Vol. 10 (January, 1907), p. 2.

[4] *Loc. cit.* [5] *Loc. cit.*

[6] "On the Density of Solid Substances with Special Reference to Permanent Changes Produced by High Pressure," *Jour. Amer. Chem. Soc.*, Vol. 34 (1912), pp. 563–84.

The method of weighing the fragment sample in water is used by the writer as it is more convenient, does not require any special apparatus, and the errors due to weighing in water can be made very small. In weighing the samples care should be taken not to trap any bubbles of air on the surface of the specimen. These bubbles can easily be seen and removed with a small camel's-hair brush. It is always well to take the sample out of the water, submerge it again, and check the previous weighing, each time examining the entire surface of the specimen for air bubbles, while the sample is in the water.

THERMOSTAT FOR PYCNOMETERS

Figure 1 shows the thermostat with the thermometer *B*; mercury thermal regulator *D;* the different parts of the stirring apparatus *G*, *H*, and *I*; the heating lamp *J* in the back of the thermostat; and the pycnometer *F* with its support *E* in front. The containing vessel *M* is a 6-gallon stone jar.

The thermometer is graduated to tenths of a degree so that the temperature can be estimated to hundredths of a degree. The mercury thermal regulator consists of a double U-bent glass tube with a capillary tube at one end and a stopcock just above the water surface close to the other end. The stopcock is shown above the support *A* in the figure, but in actual use it is below the support *A*, so that there will be no mercury column to be exposed to fluctuations of room temperature. The bent glass tube is filled with mercury by opening the stopcock. The height of the mercury in the capillary tubes is also adjusted by letting mercury in or out through the stopcock. The device *C* is a mounted and adjustable contact screw made of brass with a short platinum wire at the end for the electric contact. The other electrical contact is a platinum wire fused in the glass tube at *D*. The regulator can be made more sensitive by using a liquid of high coefficient of expansion as alcohol in the upper part of the central bend of the glass tube. This regulator is connected to a relay, which makes and breaks the current to the lamp.

The stirring device consists of a shaft and propeller, *H*, mounted in the center of a copper cylinder open at the top and bottom. The blades of the propeller are so bent that when the motor starts

the warmer water from the lamp is pumped into the cylinder from the top and thoroughly mixed with colder water coming in from the other side, as is shown by the arrows. The water then spreads out

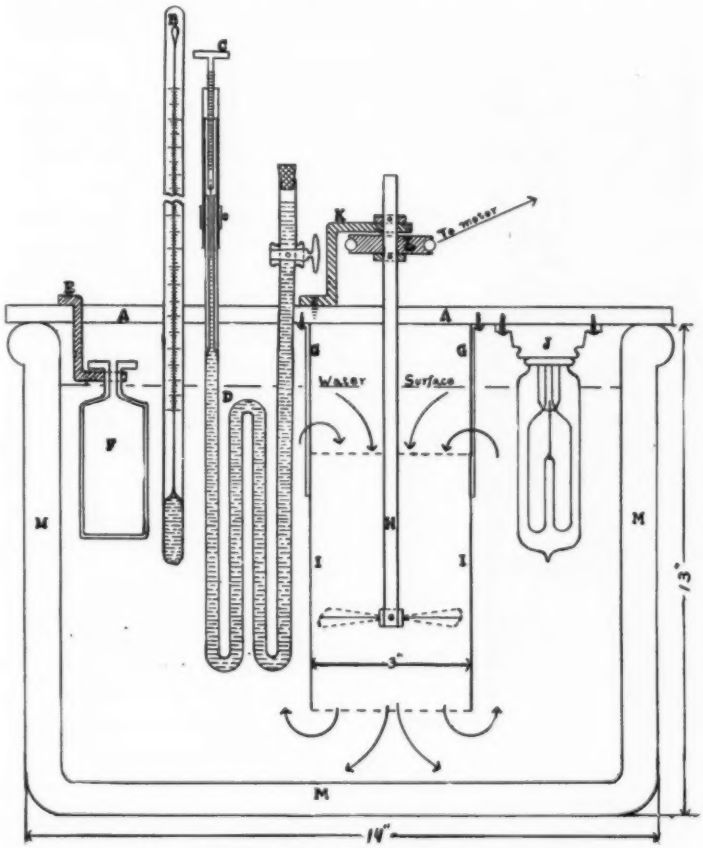


FIG. 1.—Thermostat for pycnometers

over the bottom of the jar and rises toward the surface to repeat its circuit. This method of stirring gives a very uniform temperature in every part of the thermostat, except the portion between the lamp and stirring apparatus.

SOXHLET'S EXTRACTION APPARATUS

In case there is oil in the fragment that is crushed, the oil is either burned out by placing the crushed sample in a platinum crucible or it is dissolved by a solvent, as petroleum ether, carbon bisulphide, or carbon tetrachloride, in a Soxhlet's extraction apparatus.

FIG. 2.—Soxhlet's extraction apparatus for dissolving oil from the crushed samples

Figure 2 shows the Soxhlet's extraction apparatus with porous alundum thimble containing crushed oil sand. The thimble is mounted inside *B* on a glass support. The solvent is poured into the flask *A* where it is heated by an electric stove. The vapors from the heated solvent pass up into the condenser where it condenses and drops down into the alundum thimble containing the crushed oil sand and passes out through the pores of the thimble into the vessel *B* carrying part of the dissolved oil with it. When the solvent with its dissolved oil reaches the top of the siphon *C*, the entire liquid in vessel *B* is siphoned out into the flask *A*. The foregoing process is again repeated, bringing pure solvent free from oil into contact with the oil sand. The foregoing process is continued until all the oil is removed from the sample. It makes a very convenient method and gives the crushed oil sand a thorough washing each time with the solvent free from oil. There are several modified forms of the Soxhlet's extraction apparatus. In some of these the solvent passes directly from washing the oil sand into the flask *A*. Wiley's extraction apparatus is a simple and effective type and permits weighing of both the residue and extracted matter.

It was possible to burn out the oil in many cases as most of the samples consisted of practically pure quartz.

ADVANTAGES OF METHOD ADOPTED

The method used will determine the pore space of oil- and gas-bearing sands in about one-tenth the time it takes by the water-absorption method, and is more accurate. In most cases it would be impossible to determine the pore space of the samples by water absorption with sufficient accuracy even for commercial use, on account of the small size and lack of solidity of most of the available fragments. Pore-space determinations can be made of chunk samples that weigh 3 gm. with an error of less than 0.5 per cent. The pore space of a chunk sample weighing 0.6 gm., the grains of which will pass through a No. 35 mesh sieve, less than 0.4 mm. in diameter (and most grains of oil and gas sands will pass through a mesh of this size), usually can be determined with sufficient accuracy for commercial use.

One of the chief sources of error in determining the pore space of a small sample by water absorption is that the quantity of water that may be taken from the pores or left on the surface in drying the sample may be a large percentage of the total amount of water absorbed. It is also quite difficult to clean thoroughly oil- and gas-bearing fragments of sands from their oil, water, and gas, as well as to saturate them with water after they have been cleaned. Another difficulty met in loosely connected grains of a sample is that the sample may disintegrate when it is placed in water. These difficulties and sources of error are eliminated by this method, which is used in the United States Geological Survey. Figure 3 shows apparatus for determination of pore space.

METHOD OF BREAKING THE FRAGMENT SAMPLE INTO ITS INDIVIDUAL GRAINS FOR SIEVING

The same method which was used for selecting representative samples for porosity tests, was used for selecting representative samples for the determination of the percentage distribution of diameter of grains. In most cases the same sample which was used for the determination of porosity was taken for the determination of sizes of grains. The oil was always removed from the sample before sieving to prevent the grains from cohering on the sieves.

The breaking up of the fragment into its separate grains for sieving was easily accomplished for samples whose grains were loosely cemented together, but it was very difficult to break more indurated samples into their individual grains without breaking an appreciable number of grains or leaving small aggregates of grains.

The general procedure for sieving was to place the sieves in regular order of size of mesh one on top of the other with the sieve of smallest mesh at the bottom. The mesh of the top sieve is chosen of sufficient size so that all the grains of the sample will easily

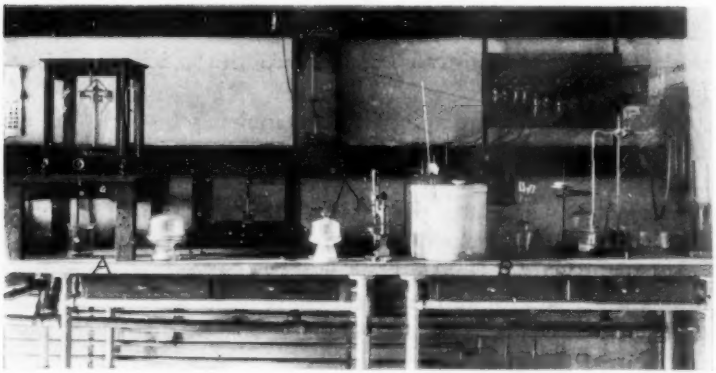


FIG. 3.—Apparatus for the determination of pore space: *A*, apparatus for finding the volume of chunks of oil sands; *B*, apparatus for finding the volume of the grains.

pass through it. In case the sample is very hard and indurated only a few grams (2–3 gm.) should be used at a time for sieving. In some cases an acid or alkali solution can be used quite successfully to separate the grains as a dilute solution of hydrochloric acid will completely disintegrate a sample of sandstone where the cementing material is calcite or lime. Soaking the sample in a solution of caustic soda has been used with some success on other samples where the cementing material was silica.

The mortar and pestle are used for most samples of oil- and gas-sand samples to separate the samples into their individual grains. A hard rubber or bakelite pestle is generally used and is

not so likely to break individual grains as the porcelain, agate, or glass pestle. Great care should be taken in applying just enough pressure or sufficient impacts with the pestle to break the sample. As soon as it is broken into a number of pieces the contents of the mortar should be poured into the top sieve in order to separate the larger pieces from the smaller and prevent crushing of any individual grains, which have become separated. The same process of breaking the pieces left on the top sieve is repeated until all of the sample has passed through it. This process of separating the fragments into smaller fragments and into their individual grains on each sieve is continued through the series. The sieves are shaken each time the contents of the mortar is emptied into the top sieve.

Before breaking the fragments in the mortar they are examined with a binocular microscope to see if they have been broken into their individual grains. As soon as the individual grain stage is reached on any sieve the breaking process is stopped.

This method is much better than to try to break the fragment sample into its individual grains at one time, as in indurated samples many of the larger grains will be crushed before the aggregates of smaller grains can be separated and large errors in the distribution of sizes of grains will result. Two independent workers, working by this method of breaking the indurated samples in stages of small quantities of the sample used, especially when the fragments become small and of repeated sorting of sizes, are able to check each other within ± 1 or ± 2 per cent.

The writer acknowledges that in case of very hard cemented samples it is very difficult to break the sample into its individual grains without breaking some of the grains, but by checking the range of size of individual grains separated with the range of sizes of grains in the fragment by a binocular microscope consistent results can be obtained.

FIELDS VISITED

There has been a general field study, examination, and collection of several thousand samples of some of the oil and gas sands of Pennsylvania, Oklahoma, northern Texas, and Wyoming. An intensive field study, examination, and collection of samples were

made of the Hickman sand, Burbank field, Osage County, Oklahoma. Other samples of oil and gas sands or of associated rocks have been received for laboratory study of their texture from Pennsylvania, Ohio, Kentucky, Illinois, Kansas, Oklahoma, Texas, Louisiana, New Mexico, Wyoming, and California. Pore-space determinations have been made of over 300 chunk samples from 150 oil- and gas-producing wells and 10 outcrops of producing formations. The distribution of diameters of grains has been determined for 60 of these samples from 50 wells. Some of the data on percentage of pore space, specific gravity of grains, distribution of diameters of grains, field information on wells such as data on production, shooting, and thickness of sands are given in the accompanying tables.

OIL SANDS FROM PENNSYLVANIA

A general field study of various oil sands of northwestern Pennsylvania fields was made in October, 1920, and samples of oil sands were collected from 15 producing wells. The producing sands from which chunk samples were collected were the Bradford, Thirty-Foot, Third, Bowlder, Fourth, Fifth, and Speechley. The results of determinations of pore space made on 43 selected samples of various texture types are given in Table I. The pore space by volume of the samples representing pay sands varied from about 7 to 19 per cent. The specific gravity of the grains of the samples from the oil sands varied from 2.62 to 2.70. The specific gravity of a sample of shale above the Speechley sand (reference No. 52) was found to be 2.76.

The sizes of grains of these sands varied from very fine sand to coarse pebbles imbedded in a matrix of fine cementing material.

The Bradford oil sand varies in porosity from 15 to 19 per cent. The average sizes of grains (about 0.12 mm. in diameter) from different samples of this sand are quite uniform.

The Speechley oil-sand samples consisted of very fine sand grains. Practically all of the grains would pass through a 200-mesh sieve (less than 0.074 mm.).

The samples from the Bowlder, Thirty-Foot, Third, Fourth, and Fifth oil sands usually consisted of grains with a large range of sizes.

The diameters of grains of some of the larger pebbles were sometimes over 1 cm. The percentage of pore space in these samples would depend largely upon the quantity and mode of occurrence of the fine material between the larger grains, as well as upon the distribution of the diameters of grains of this finer material.

The samples were tested with hydrochloric acid for carbonates, and effervescence occurred in 8 samples out of the 38 tested.

The average percentage of pore space of the samples that effervesced was about the same as the average percentage of pore space of those that did not effervesce.

G. B. Richardson co-operated with the writer and gave valuable suggestions on the field work in Pennsylvania. K. K. Kimball collected some of the samples of oil sand. John G. Douglas assisted in making the determinations of pore space of some of the samples from Pennsylvania.

OIL AND GAS SANDS OF WYOMING

A general field study was made of some of the oil and gas sands of Wyoming during May and June, 1920. Samples were collected from 13 producing wells and 5 outcrops of producing sands. The results of determinations of porosity made on 43 of the samples representing the different texture types are given together with field data on thickness of sand and production in Table I following on pages 740 to 759 inclusive.

TABLE I

PERCENTAGE OF TOTAL PORE SPACE, SPECIFIC GRAVITY OF GRAINS, AND FIELD INFORMATION ON WELLS, SUCH AS DATA ON PRODUCTION, SHOOTING, AND THICKNESS OF SANDS

Reference No.	Location of Well	Field or Pool	Name of Sand	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Natural Production (Bbls.)	Initial Production (Bbls.)	Depth to Top and Bottom of Shot (Ft.)	Size of Shot (Qt.)	Samples, How Collected	Pore Space Percentage by Volume	Total Wt. of Sple. (Gm.)	Sp. Gr. of Grains	Percentage of Oil Burned out	Sp. Gr. of Oil	Remarks
	Oil Sands from Pennsylvania															
47..	William C. Kennedy Co., well in McKean County	Bradford	Bradford	.....	.....	.....	8	.....	.....	Shot out	18.6	23.665	2.665	.....	.....	
44..	Kendall Refining Co., well No. 6, on Steward farm	Bradford	Third Bradford	.....	.....	.....	.....	.....	.....	Shot out	15.7 18.5 16.0 14.9 15.1	13.305 11.946 27.409 21.504 17.829	2.669 ..... 2.662 2.683 2.653	.....	.....	
142..	Sample from well No. 1, on Cornelia Short farm, New Kensington Quadrangle	.....	Fifth	Samples from 2,300 ft.	.....	.....	.....	.....	.....	Shot out	6.2 13.2 12.2	16.333 27.588 6.309	2.854 2.645 2.648	.....	.....	[1]
143..	Samples from well on William and Thomas Baker farm, Butler County	.....	Fourth and top sand	.....	.....	.....	.....	.....	.....	Shot out	15.9 11.5 10.6	6.627 6.006 14.840	2.646 2.651 2.644	.....	.....	
144..	Samples from well No. 2, on W. J. Clemdemning farm, West Deer Township, Allegheny County	.....	Bowlder	.....	.....	.....	.....	.....	.....	Shot out	12.6 8.3 6.2	9.133 12.214 21.990	2.647 2.641 2.692	.....	.....	[2] [3] [4]
105..	South Penn Oil Co., Nancy Gibson well No. 3(?), about 2 mi. NW. of Wildwood, Allegheny County	.....	Third	1,762–90	28	.....	1 or 2	.....	.....	Shot and bailed out	4.8 8.1 4.6 7.5	12.719 13.428 28.455 13.845	2.633 2.624 2.627 2.631	.....	.....	[5] [6] [7] [8]

[1] Sample, shaley sand and cap rock
[2] Grains, loosely cemented
[3] Sample, more cemented
[4] Sample, tightly cemented
[5] Hard cap rock
[6] Sample from better pay
[7] Sample, hard cemented
[8] Sample from better pay

111..	Fisk & Fowler well No. 3, on Paul Redrick farm, about 1¼ mi. NW. of Wildwood, Allegheny County	.....	Third	1,810–?	.....	.....	5 to 10; some gas	.....	.....	Bailed out after shot	8.2 6.1 6.6 9.1 7.6	10.781 12.551 8.239 4.870 8.888	2.627 2.632 2.646 2.643 2.644	....	....	[1] [2] [3] [4] [5]
109..	Ridgeview well No. 1, on L. V. Hoffman farm, 1 mi. SE. of Glenshaw	Glenshaw	Thirty-Foot	1,843–58	15	.....	25; strong gas pressure	.....	.....	Shot and bailed out	9.5 9.3 9.0 9.8	15.021 11.252 26.275 3.569	2.648 2.649 2.645 2.649	....	....	
110..	American Natural Gas Co., well No. 4, on Park estate, Allegheny Co. Well completed Oct. 8, 1920	Glenshaw	Thirty-Foot	.....	.....	.....	25	.....	.....	Bailed out	9.5 7.2 8.7	3.118 8.272 10.061	2.622 2.649 2.648	....	....	[6] [7]
125..	Well No. 1, on W. G. Montgomery farm, Clinton Township, Butler County	.....	.....	Sample from 1,720 ft.	.....	.....	.....	.....	.....	Shot out	10.4 12.0 10.6	12.572 14.368 27.178	2.645 2.646 2.647	....	....	
107..	Well No. 1, on Montgomery farm, Clinton Township, Butler County, 1½ mi. SW. of Ivywood	.....	Third	1,699–1,717	18	.....	10	.....	.....	Shot and bailed out	9.1 5.0	2.475 4.711	2.652 2.644	....	....	[8] [9]
108..	Probably McFarland well No. 1, Dorseyville, Allegheny County	Dorseyville	.....	1,910±	.....	.....	.....	.....	.....	Bailed out	8.6	3.081	2.647	.....	.....	
106..	Well No. 1, on Short farm, close to Wildwood, Allegheny County	.....	Third	1,720–?	.....	.....	.....	.....	.....	.....	5.0 6.0	7.702 3.786	2.652 2.643	.....	.....	
113..	Marshall well No. 8, New Kensington Quadrangle, Allegheny County	.....	Bowlder or Third	.....	.....	.....	.....	.....	.....	Shot out	4.4	16.641	2.676	.....	.....	[10]
114..	Fort Kelly well No. 22, 1 mi. west of Bruin, Butler County	.....	Speechley	2,032–49	17	.....	50,000 cu. ft.; 3 bbls.	.....	50	Shot out	15.4 13.0 4.3	4.392 3.022 8.556	2.696 2.681 2.763	....	....	[11] [12]

[1] Sample from better pay
[2] Sample, hard cemented
[3] Sample, large grains cemented
[4] Sample from better pay
[5] Samples from top to bottom of producing sand
[6] Sample, pay, loosely cemented
[7] Sample, more cemented
[8] Sample from top of sand
[9] Well completed Feb., 1920
[10] Sample, hard cemented, not pay
[11] Pay, very fine grained and hard sandstone
[12] Sample, shale above pay sand

TABLE I—*Continued*

Reference No.	Location of Well	Field or Pool	Name of Sand	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Natural Production (Bbls.)	Initial Production (Bbls.)	Depth to Top and Bottom of Shot (Ft.)	Size of Shot (Qt.)	Samples, How Collected	Pore Space Percentage by Volume	Total Wt. of Sple. (Gm.)	Sp. Gr. of Grains	Percentage of Oil Burned Out	Sp. Gr. of Oil	Remarks
	Oil Sands from Ohio															
51..	The Reger Oil Co., Snider well No. 1, Rumley Township, Harrison County. Well completed Oct. 20, 1919	.....	Berea	.....	.....	.....	1; little gas	.....	30	Shot out	17.2 17.1	9.117 8.167	2.673	2.1	0.80	
52..	The Reger Oil Co., Simon Snider well No. 3, Rumley Township, Harrison County. Well completed April 1, 1920	.....	Berea	.....	.....	.....	4; very little	.....	30	Shot out	15.4	6.254	2.677	1.6	0.80	
	Oil Sands from Illinois															
	Sample from Deter Well, near Carlyle	.....	Carlyle	1,026–	.....	.....	200	.....	.....	.....	27.6 20.6 22.0	14.614 9.703 7.580	2.662 2.661	.....	.....	1
	Oil and Gas Sands from Wyoming															
89..	Midwest Refining Co., Whiteside well No. 18, Sec. 9, T. 33 N., R. 76 W., Converse County	Big Muddy	"First Wall Creek"	3,102–87	150–80	.....	125	.....	.....	Bailed out	20.2 17.4 20.0	14.678 18.158 23.906	2.631	....	....	
90..	Midwest Refining Co., well No. 11 Glenrock Sheep Lease, Sec. 4, T. 33 N., R. 76 W., Converse County	Big Muddy	"First Wall Creek"	3,040–?	150–80	.....	205	.....	.....	Bailed out	23.4	3.002	2.632	.....	.....	

[1] Oil formation fairly uniform in porosity with one parting of shale running through it. Oil above shale

[1] Oil formation fairly uniform in porosity with one parting of shale running through it. Oil above shale

91..	Midwest Refining Co., well No. 14, Sec. 3, T. 33 N., R. 76 W., Converse County	Big Muddy	"First Wall Creek"	3,140–?	150–80	.....	180	.....	.....	Bailed out	20.8	3.002	2.629	.....	.....	
93..	Midwest Refining Co., well No. 31, Sec. 36, T. 40 N., R. 79 W., Natrona County	Salt Creek	"First Wall Creek"	1,235	120–30	.....	150	.....	.....	Cuttings from 1,300 ft.	19.8	9.232	2.721	.....	.....	
149..	Bair Oil Co., well No. 32, Sec. 10, T. 26 N., R. 29 W., Sweetwater County.	Lost Soldier	"First Wall Creek"	289–313	24	.....	150	.....	.....	Shot out	20.1	13.017	.....	6.4	0.86	
151..	Sample from Sec. 23, T. 27 N., R. 89 W., Carbon County	.....	"First Wall Creek"	.....	.....	.....	.....	.....	.....	Outcrop	19.9	22.917	.....	.....	.....	
55..	Bair Oil Co., well No. 12, Sec. 11, T. 26 N., R. 90 W., Sweetwater County	Lost Soldier	.....	.....	40	.....	75	.....	.....	.....	17.5	7.032	2.659	11.4	0.86	
124..	Well in Sec. 9, T. 46 N., R. 63 W., Weston County	Osage	Newcastle	40–?	60–?	.....	Less than 3	.....	.....	Diamond drilled core	22.6	3.206	2.646	6.0	0.84	[2]
											26.0	5.514	2.696	5.9	0.84	[3]
											14.7	15.931	.....	.....	.....	[4]
											15.3	12.502	.....	.....	.....	[5]
											19.8	7.812	2.646	6.2	0.84	[6]
											14.5	14.079	.....	.....	.....	[7]
											12.5	.....	.....	.....	.....	[8]
											13.3	8.842	2.703	.....	.....	[9]
											19.5	6.638	.....	.....	.....	[10]
											15.4	3.384	2.676	.....	.....	[11]
											11.3	.....	.....	.....	.....	[12]
											15.2	.....	.....	.....	.....	
76..	Sinclair Oil Corp., well No. 4, SE. 1, Sec. 19, T. 46 N., R. 64 W., Weston County	Osage	Newcastle	1,415–50	35	25	.....	.....	.....	Drill cuttings	23.1	0.461	2.671	10.1	0.84	[13]
											23.6	0.458				
											21.3	0.462				
98..	Outcrop near Moorcraft, Crook County, near oil seep	.....	Newcastle	.....	.....	.....	Asphalt stained	.....	.....	Outcrop	23.9	8.280	2.650	.....	.....	
											24.8	14.730	.....	.....	.....	
73..	Outcrop near Newcastle, Weston County	.....	Newcastle	.....	.....	.....	.....	.....	.....	Outcrop	24.1	7.748	.....	.....	.....	
											19.0	10.330	2.642	.....	.....	

[1] From first sand at 40 ft.
[2] From second sand at 64 ft.
[3] From second sand at 70 ft.
[4] From third sand at 87 ft.
[5] From third sand at 95 ft.
[6] From third sand at 96 ft.
[7] From third sand at 97 ft.
[8] From Skull Creek at 153 ft.
[9] Stray sand from Skull Creek. Shale at 185 ft.
[10] Stray sand from Skull Creek. Shale at 195 ft.
[11] Stray sand from Skull Creek. Shale at 197 ft.
[12] Top of Dakota sandstone at 300 ft.
[13] Pay in streaks, samples from best pay

TABLE I—*Continued*

Reference No.	Location of Well	Field or Pool	Name of Sand	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Natural Production (Bbls.)	Initial Production (Bbls.)	Depth to Top and Bottom of Shot (Ft.)	Size of Shot (Qt.)	Samples, How Collected	Pore Space Percentage by Volume	Total Wt. of Spls. (Gm.)	Sp. Gr. of Grains	Percentage of Oil Burned Out	Sp. Gr. of Oil	Remarks
	Oil and Gas Sands from Wyoming															
77..	Outcrop near Osage, Sec. 10, T. 46 N., R. 63 W., Weston County	.....	Newcastle	.....	.....	.....	.....	.....	.....	Outcrop	8.8 23.5 22.3 23.2 21.4	7.367 12.365 10.713 5,408 11.506	2.676 .... 2.654	.....	.....	[1]
86..	Ohio Oil Co., Converse Sheep Co., well No. 1, SE. ¼, Sec. 32, T. 36 N., R. 65 W., Niobrara County	Lance Creek	Newcastle	2,900–2,915	15	.....	60	.....	.....	Drill cuttings	20.7 14.9	1.200 1.378	..... 2.686	.....	.....	[2]
140..	Midwest Refining Co., well No. 1, NE. ¼, Sec. 24, T. 46 N., R. 64 W., Weston County	.....	Newcastle	1,435	.....	.....	.....	.....	.....	Shot out	19.0 19.5	9.155 11.908	2.646	8.3 6.7	0.84	[3]
152..	Outcrop of gas sand, Sec. 12, T. 27 N., R. 89 W., Carbon County	Lost Soldier	Newcastle	.....	35	.....	.....	.....	.....	Outcrop	17.9 12.5	29.095 18.602	....	.....	.....	
150..	Producers & Refiners Oil Co., gas well in Sec. 7, T. 26 N., R. 89 W., Carbon County, Wertz-dome	Ferris District	Newcastle	3,400–3,435+	35+	.....	30,000,000 cu. ft.	.....	.....	Blown out by gas	11.4	12.433	.....	.....	.....	
128..	Midwest Refining Co., well No. 13, on Ridgely Lease, Grass Creek, Hot Springs County	Grass Creek	Frontier formation	.....	.....	.....	165	.....	.....	.....	27.0	6.757	2.646	.....	.....	
118..	Ohio Oil Co., well No. 5, Sec. 9, T. 33 N., R. 76 W., Converse County	Big Muddy	"First Wall Creek"	Sample from 3,050 ft.	162	.....	300	.....	.....	Bailed out	21.5 20.7	21.402 15.817	2.632	.....	.....	[4]

[1] Top member, hard and calcareous
[2] Samples from 5 feet below top of sand
[3] Samples from 1,435–46
[4] Pay in streaks through the 162 ft. of sand

	Oil Sands from Kentucky																
	Oil sand from well in Middle Devonian (Onondaga?), Ravena	.....	.....	.....	.....	.....	.....	.....	.....	Mined out	10.4 11.9	46.992 19.226	2.848	4.0	0.87	[1]
162..	Sample from well on J. N. Steely farm, 1 mi. north of Williamsburg	.....	Williamsburg	800–?	.....	.....	.....	.....	.....	.....	12.4	12.314	.....	.....	.....	[2]
	Oil and Gas Sands from Oklahoma																
1..	Oklahoma Producing & Refining Corp. of America, well No. 1, Sec. 34, T. 16 N., R. 10 E. Well completed Nov. 1, 1919 (Creek County)	.....	Likely Glenn or Bartlesville	.....	.....	.....	150	2,667–75	.....	Bailed out	19.7	7.265	2.719	.....	.....	
7..	Minnehoma Oil Co., well No. 14, N. ½ of SW. ¼, Sec. 16, T. 18 N., R. 7 E., Creek County. Well completed April 5, 1918	Cushing	Bartlesville	2,639–80	41	.....	600	.....	.....	Bailed out	28.9 32.0	17.107	2.684	8.7	0.81	[3]
13..	Texas Co., well on Zeke Moore farm, Sec. 8, T. 17 N., R. 12 E., Creek County	.....	Bartlesville	.....	50–60	.....	.....	.....	.....	Shot out	21.2	17.553	2.642	.....	.....	
17..	Barnsdall Oil Co., well No. 6, NE. ¼, Sec. 5, T. 24 N., R. 10 E., Osage County	Pershing	Bartlesville	1,988–2,047	59	.....	30	.....	.....	Shot out	15.5 16.0 15.4	11.887 28.790 29.418	2.685	.....	.....	
19..	James H. Gardner, Spencer, and others, well No. 1, near center SW. ¼, Sec. 19, T. 25 N., R. 9 E., Osage County	.....	Bartlesville	2,267	12, in sand	75	.....	.....	.....	Drill cuttings	37.7 38.7	0.691 0.666	2.638	.....	.....	
20..	Testlog Oil Co., well No. 12, Sec. 19, T. 24 N., R. 10 E., Osage County	Pershing	Bartlesville	2,079–2,132	53	.....	50	.....	340	Shot out	14.1	6.112	2.705	.....	.....	
21..	Marland Refining Co., well No. 1, NW. ¼, Sec. 34, T. 25 N., R. 9 E., Osage County	.....	Bartlesville	2,090–2,118	28	.....	200	2,088–2,118	.....	Shot out	13.5	10.489	2.685	.....	.....	[4]

[1] Sample consisted of lime from shaft in oil formation
[2] Sample from basal Pottsville horizon
[3] The gas pressure in this well was very low as it was the fourteenth to be drilled on a tract of 80 acres. Some of the other wells had been producing for several years. If this well had been drilled first, its initial production would probably have been over 1,000 bbls., according to Mr. E. Kluth, geologist, Minnehoma Oil Co.
[4] Sample, hard and fine grained, not representative of good pay

[1] Pay in streaks through the 162 ft. of sand

TABLE I—*Continued*

Reference No.	Location of Well	Field or Pool	Name of Sand	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Natural Production (Bbls.)	Initial Production (Bbls.)	Depth to Top and Bottom of Shot (Ft.)	Size of Shot (Qt.)	Samples, How Collected	Pore Space Percentage by Volume	Total Wt. of Sple. (Gm.)	Sp. Gr. of Grains	Percentage of Oil Burned Out	Sp. Gr. of Oil	Remarks
	Oil and Gas Sands from Oklahoma															
45..	Plover Drilling Co., well No. 1, NE. ¼, Sec. 20, T. 26 N., R. 11 E, Osage County	.....	Bartlesville	1,570-91	21	10	125	.....	80	Shot out	18.8	18.180	2.758	.....	32° Baumé	
48..	Rood Oil Corp., well No. 14, SW. ¼, Sec. 4, T. 24 N., R. 10 E., Osage County	Pershing	Bartlesville	.....	.....	.....	Dry hole	.....	.....	Drill cuttings	15.2	7.493	2.700	.....	.....	[1]
49..	Rood Oil Corp., well No. 9, SW. ¼, Sec. 4, T. 24 N., R. 10 E., Osage County	.....	Bartlesville	.....	.....	.....	.....	.....	.....	.....	14.1	16.190	2.688	.....	.....	
25..	Cosden Oil & Gas Co., well No. 1, SE. ¼, Sec. 23, T. 25 N., R. 9 E., Osage County. Well completed Nov. 18, 1919	.....	Bartlesville	2,158-63	5	.....	102	2,158-63 2,158-71	25 75	Shot out	16.4	2.688	2.687	.....	.....	
132..	H. V. Foster, well No. 32, Osage County	Pershing	Bartlesville	.....	.....	.....	150	.....	.....	Shot out	12.1	15.070	2.68	2.0	0.85	[2]
135..	Graham & Bird, well No. 4, NE. ¼, Sec. 6, T. 24 N., R. 10 E., Osage County	Pershing	Bartlesville	.....	.....	.....	.....	.....	.....	Shot out	15.6	21.456	.....	8.4	0.85	
135..	Graham & Bird, well No. 4, NE. ¼, Sec. 6, T. 24 N., R. 10 E., Osage County	Pershing	Bartlesville	.....	.....	.....	.....	.....	.....	Shot out	7.6	32.727	.....	.....	.....	[3]

[1] Drill cuttings from 2,072 to 2,079 ft.

[2] Sample, hard and cemented, not good pay

[3] Sample, hard cap rock

133..	New England Pipe Line Co., well No. 25, SE. ¼, Sec. 5, T. 24 N., R. 10 E., Osage County	Pershing	Bartlesville	2,022–76	54	.....	25	.....	.....	Shot out	12.4	9.520	.....	4.2	0.85	
134..	New England Pipe Line Co., well No. 24, SE. ¼, Sec. 5, T. 24 N., R. 10 E., Osage County	Pershing	Bartlesville	2,039–63	24	.....	.....	.....	.....	.....	9.5	1.685	.....	.....	.....	[1]
53..	Rood Oil Corp., well No. 2, NE. ¼, Sec. 20, T. 26 N., R. 10 E., Osage County	.....	Bartlesville	1,572–99	27	10	100	.....	.....	Shot out	17.1 15.9 19.7	13.040 9.039 7.876	.... 2.692	4.7 ..... 7.6	0.85	
54..	Rood Oil Corp., well No. 3, NE. ¼, Sec. 20, T. 26 N., R. 10 E., Osage County	.....	Bartlesville	1,577–1,603	26	10	200	.....	100	Shot out	18.1 17.7	6.813 16.067	2.868	7.7	0.85	
122..	Manhattan Oil Co., well in NE. ¼, Sec. 25, T. 24 N., R. 11 E., Osage County	.....	Bartlesville	1,705–67	62	.....	.....	.....	.....	.....	16.7 15.4	2.766 11.072	2.671	....	....	
3..	Twin State Oil Co., Hughes well No. 1, NW. ¼, of SE. ¼, Sec. 12, T. 20 N., R. 7 E., Pawnee County	.....	Skinner(?)	2,420–2,520	100	.....	.....	.....	.....	Blown out by gas	13.9	8.602	2.693	.....	.....	
4..	Pomeroy-Hamilton Co., probably Besser well No. 1, Sec. 24, T. 19 N., R. 9 E., Pawnee County. Well completed March 20, 1919	Keystone	Wayside(?)	1,150–90	40	15	100	.....	.....	Shot out	12.0	8.944	2.719	.....	.....	
5..	Pomeroy-Hamilton Co., well No. 2, Sec. 25, T. 20 N., R. 9 E., Pawnee County	.....	Layton gas sd.	853–58	5	.....	I.R.P., 255 lb.	.....	.....	Blown out by gas	22.1	8.169	2.659	.....	.....	
8..	Minnehoma Oil Co., well No. 6, SE. ¼, Sec. 14, T. 22 N., R. 4 W., Garfield County. Well completed Oct. 22, 1919	Garber	.....	1,784–1,800	16	100	.....	.....	.....	Drill cuttings	16.4 20.3	1.021 0.990	2.685	.....	.....	
10..	Pomeroy-Hamilton Co., well No. 1 in Appalachia Township, Pawnee County	Keystone	Wayside(?)	1,119–64	35	.....	100	1,117–1,162.5	200	Shot out	18.5 18.3 20.9	16.630 18.164 16.918	2.681	....	....	

[1] Sample, very poor, very fine grained, no oil in sample

TABLE I—*Continued*

Reference No.	Location of Well	Field or Pool	Name of Sand	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Natural Production (Bbls.)	Initial Production (Bbls.)	Depth to Top and Bottom of Shot	Size of Shot (Qt.)	Samples, How Collected	Pore Space Percentage by Volume	Total Wt. of Sple. (Gm.)	Sp. Gr. of Grains	Percentage of Oil Burned Out	Sp. Gr. of Oil	Remarks
	Oil and Gas Sands from Oklahoma															
11..	Pomeroy-Hamilton Co., well No. 6 on Carter farm, SE. ¼, Sec. 24, T. 20 N., R. 9 E., Pawnee County. Completed Oct. 24, 1919	Keystone	Wayside(?)	1,176–1,235	59	.....	28	1,176–1,227	220	Shot out	7.2	11.917	2.706	.....	.....	[1]
12..	Pomeroy-Hamilton Co., W. T. Besser well No. 7, SW. ¼, Sec. 24, T. 20 N., R. 9 E., Pawnee County. Completed Sept. 20, 1919	Keystone	Wayside(?)	1,160–1,223	63	.....	81	1,164–1,221	220	Shot out	6.7	21.470	2.703	.....	.....	[2]
18..	Kanola Oil Co., well No. 5, Emma Telmasse Lease, NE. ¼, Sec. 3, T. 16 N., R. 7 E., Creek County. Well completed Dec. 20, 1916	.....	Layton	1,495–1,525	30	.....	500	.....	.....	Shot out	26.3	6.435	2.667	.....	.....	
42..	Natural Resource Developing Co., well in Sec. 34, T. 25 N., R. 9 E., Osage County	.....	Stray	Top of sand, 1,536	.....	.....	300	.....	90	Shot out	15.2	13.420	2.731	.....	.....	
23..	Carter well No. 1, Sec. 17, T. 2 S., R. 7 W., Stephens County	.....	Wilson	1,380	.....	.....	175	.....	.....	Flowed out with oil	20.0	0.413	2.699	.....	.....	
24..	Gladys-Bell Oil Co., Monroe well No. 1, Sec. 29, T. 17 N., R. 15 E., Wagoner County	Stone Bluff	.....	1,144–62	18	.....	200	.....	.....	Bailed out	16.5	11.946	2.672	.....	.....	

[1] Sample, hard and cemented sandstone, not good pay

[2] Sample, hard and cemented sandstone, not good pay

26..	Texas Co., well in NE. ¼, Sec. 6, T. 23 N., R. 13 E., Washington County	.....	Burgess	1,650±	18	.....	90	.....	.....	Shot out	16.4 22.0	6.250 4.364	2.673	.....	.....	
27..	Cosden Oil & Gas Co., well No. 1, SE. ¼, Sec. 29, T. 22 N., R. 10 E., Osage County	.....	Cleveland	.....	.....	.....	50	.....	100	Shot out	17.7	22.358	2.686	.....	.....	
28..	Heggem & Davis, well No. 2, Sec. 17, T. 15 N., R. 16 E., Muskogee County. Well completed April 18, 1919	.....	Wayside(?)	1,304–?	.....	.....	500	.....	.....	Bailed out	20.1	9.732	2.693	.....	.....	
29..	Pomeroy-Hamilton Co., well No. 2, Sec. 25, T. 20 N., R. 9 E., Pawnee County	.....	Wayside(?)	1,116–61	45	.....	52.5	.....	200	Shot out	15.8	9.212	2.720	.....	.....	1
30..	The Prairie Oil & Gas Co., Sam King well No. 9, Sec. 30, T. 18 N., R. 12 E., Creek County	.....	Glenn sand	1,541–92	51	.....	300	1581.2–1589.6	20	Shot out	21.4	13.454	2.697	.....	.....	
50..	Oil Issues Co., Pawnee County	Keystone	Wayside	.....	.....	.....	.....	.....	.....	.....	17.4 22.0	16.194 16.800	2.702	.....	.....	
100..	Rockland Dillard, well No. 6, Sec. 22, T. 4 S., R. 2 W., Carter County	Hewitt	Hewitt	1,484–87	.....	.....	.....	.....	.....	.....	19.4 17.3	1.433 0.475	2.643	.....	.....	2 3
102..	Sample from above well No. 6	Hewitt	Hewitt	1,408–35	.....	.....	.....	.....	.....	Drill cuttings	21.7	0.379	.....	.....	.....	4
	Kingwood Oil Co., well No. 46, NW. ¼, Sec. 16, T. 11 N., R. 11 E., Okfuskee County	Deaner	Deaner	Sample from 2,522 ft.	90±	800	.....	.....	.....	Bailed out (?)	12.5	3.605	2.695	.....	.....	
	Empire Gas & Fuel Co., well No. 8, SW. ¼, T. 11 N., R. 11 E., Okfuskee County	Deaner	Kingwood	2,657–?	30±	.....	.....	.....	.....	Bailed out (?)	15.7 16.0	..... 3.280	..... 2.707	.....	.....	5
148..	Osage Developing Co., well No. 27, Sec. 35, T. 29 N., R. 11 E., Osage County	.....	Red	900±	.....	.....	5	.....	.....	Shot out	7.5	8.213	.....	.....	.....	
	Sample from well in Osage County	.....	Red	.....	.....	.....	.....	.....	.....	.....	18.4 15.9	9.329 22.140	....	5.7 4.5	0.83 0.83	
	Sample from well in Osage County	.....	Red	.....	.....	.....	.....	.....	.....	.....	10.9 17.5	17.229 24.075	2.762 2.728	.....	.....	

[1] Shot from top to bottom of sand
[2] Sample from second layer
[3] Sample from first screw in second layer of sand
[4] Sample from top layer
[5] Samples from 2,666 ft.

TABLE I—*Continued*

Reference No.	Location of Well	Field or Pool	Name of Sand	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Natural Production (Bbls.)	Initial Production (Bbls.)	Depth to Top and Bottom of Shot (Ft.)	Size of Shot (Qt.)	Samples, How Collected	Pore Space Percentage by Volume	Total Wt. of Sple. (Gm.)	Sp. Gr. of Grains	Percentage of Oil Burned Out	Sp. Gr. of Oil	Remarks
	Oil and Gas Sands from Oklahoma															
157..	Gypsy Oil Co., well No. 4, NW. ¼, Sec. 22, T. 15 N., R. 10 E., Creek County	Slick	Dutcher	2,575–	Average, 40 ft.	.....	100	.....	.....	Shot out	.... / 11.2	..... / 17.664	.....	.....	.....	1 / 2
158..	Phillips Petroleum Co., well No. 6, SE. ¼, Sec. 16, T. 15 N., R. 10 E., Creek County	Slick	Dutcher	Sample from 2,613 ft.	.....	90	700	.....	.....	Shot out	9.0	8.176	.....	.....	.....	3
159..	Sunrise Petroleum Co., well No. 4, NE. ¼, Sec. 22, T. 15 N., R. 10 E., Creek County	Slick	Dutcher	.....	.....	.....	100	.....	.....	Shot out	9.6 / 9.1	6.709 /	.....	.....	.....	4
160..	Phillips Petroleum Co., well No. 3, NE. ¼, Sec. 8, T. 15 N., R. 10 E., Creek County	Slick	Dutcher	Sample from 2,613 ft.	.....	.....	50*	.....	.....	Shot out	14.9	4.919	.....	.....	.....	
	Oil Sand from Kansas															
6..	Well No. 21 from Inscho Lease, Sec. 13, T. 32 S., R. 14 E., Montgomery County. Well completed May 21, 1919	.....	Wayside	586–631	45	0.5	18	.....	.....	Drill cuttings	9.7	3.151	2.731	.....	.....	
	Sand from New Mexico															
22..	Carter Oil Co. Outcrop in NW. ¼, Sec. 1, T. 9 N., R. 21 E., Guadulupe County. Close to Santa Rosa, New Mexico	.....	Santa Rosa	.....	.....	.....	.....	.....	.....	Outcrop	18.0	7.807	2.640	.....	.....	

[1] Top 20 feet, Dutcher sand, very hard, seldom carries oil
[2] Sample, probably cap rock, very hard and cemented
[3] Sample very fine grained
[4] Sample, hard and cemented, probably from top of sand

[1] Top 20 feet, Dutcher sand, very hard, seldom carries oil
[2] Sample very fine grained
[3] Sample, probably cap rock, very hard and cemented
[4] Sample, hard and cemented, probably from top of sand

TABLE I—*Continued*

Reference No.	Location of Well	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Maximum Thickness of Production Sand (Ft.)	Natural Production (Bbls.)	Greatest Production in 24 Hours (Bbls.)	Size of Shot (Qt.)	Depth to Top and Bottom of Shot (Ft.)	Samples, How Collected	Pore Space, Percentage by Volume	Total Weight of Sample (Gm.)	Sp. Gr. of Grains	Percentage of Oil Burned Out	Remarks
	Oil Sands from Burbank Field, Osage County, Oklahoma													
1*B*..	Waite Phillips Co., well No. 1, SE. ¼, Sec. 33, T. 27 N., R. 6 E. Well completed April 27, 1922	2,915–88	73	46	.....	425	130	2,918–84	.....	19.0 20.2 17.0 17.0 18.2 18.5 20.4	6.493 3.915 9.874 9.108 14.394 10.381 21.448	2.708 2.699 2.735 2.691 2.700 2.707 2.715	.....	[1]
2*B*..	Waite Phillips Co., well No. 5, SE. ¼, Sec. 33, T. 27 N., R. 6 E. Well completed May 6, 1922	2,898–2,940	42	12	.....	25	60 75	2,916–40 2,914–40	.....	14.9 15.3 13.7	14.715 3.947 9.068	2.696 2.697 2.714	.... 5.6	[2]
3*B*..	Sinclair Oil and Gas Co., well No. 2, SW. ¼, Sec. 36, T. 27 N., R. 5 E. Well completed Sept. 23, 1921	2,835–95	60	43	945	1,777	20 30 40 60	..... 2,865–95 2,855–95	.....	25.8 26.9 25.1 26.2 27.4	14.715 9.317 19.790 8.906 12.332	2.692 2.718 2.688 2.732 2.694	15.9 16.0	[4] [5]
4*B*..	Sinclair Oil & Gas Co., well No. 2, NE. ¼, Sec. 1, T. 26 N., R. 5 E. Well completed June 29, 1921	2,867–2,925, bottom of well	51	43	750	1,235	10 20 30 40 60 80	....	....	22.9 16.7 20.6 31.9 17.9 32.1	....	2.745 2.688 2.717 2.708 2.692 2.704	.... 22.1 16.6 20.5	[6]
5*B*..	Producers and Refiners Corp., well No. 6, NW. ¼, Sec. 31, T. 27 N., R. 6 E. Well completed Aug. 28, 1921	2,902.5–2,964	61½	61½	930	3,050	145	2,902–54	.....	29.4 27.8 32.7	....	2.688 2.691 2.698	13.0	
6*B*..	Midland Oil Co., well No. 1, NW. ¼, Sec. 15, T. 26 N., R. 6 E. Well completed May 16, 1922	2,866–91	25	25	0	460	120	2,857–83	.....	18.4 15.9 19.7	....	2.708 2.710 2.692	....	

[1] Well shot April 27, 1922
[2] Well shot May 6, 1922
[3] Well shot May 14, 1922
[4] Well shot Sept. 23, 1921
[5] Well shot Sept. 24, 1922
[6] Producing sand consisted of alternate layers of hard and soft sand

TABLE I—*Continued*

Reference No.	Location of Well	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Maximum Thickness of Producing Sand (Ft.)	Natural Production (Bbls.)	Greatest Production in 24 Hours (Bbls.)	Size of Shot (Qt.)	Depth to Top and Bottom of Shot (Ft.)	Samples, How Collected	Pore Space, Percentage by Volume	Sp. Gr. of Grains	Percentage of Oil Burned Out	Remarks
	Oil Sands from Burbank Field, Osage County, Oklahoma												
7*B*..	Sinclair Oil & Gas Co., well No. 2, SW. ¼, Sec. 29, T. 27 N., R. 6 E. Well completed March 26, 1922	2,885–2,948	63	.....	35	340	20 30 60	2,929–54 2,918–48 2,906–48	....	21.3 18.6 17.3	2.704 2.705 2.698	.... 8.4	1
8*B*..	Prairie Oil & Gas Co., well No. 8, NE. ¼, Sec. 30, T. 27 N., R. 6 E. Well completed May 7, 1922	2,860–2,925	65	50	450	1,100	80	2,876–2,916	.....	24.5 23.3	2.698 2.706	....	
9*B*..	Phillips Petroleum Co., well No. 8, NW. ¼, Sec. 30, T. 27 N., R. 6 E. Well completed May 28, 1922	2,902–82	80	60	.....	1,100	100	2,922–82	.....	23.3	2.691	.....	
10*B*..	Carter Oil & Gas Co., well No. 4, SW. ¼, Sec. 31, T. 27 N., R. 6 E. Well completed Aug. 19, 1921	2,893–2,960	67	37	27.5	300	100	2,920–60	.....	18.1 17.3	2.693 2.691	13.3	2
11*B*..	Sinclair Oil & Gas Co., well No. 6, SW. ¼, Sec. 29, T. 27 N., R. 6 E. Well completed May 11, 1922	2,915–73	58	.....	303	330	130	2,926–78	.....	18.2 17.7	2.713 2.716	8.3 6.7	3
12*B*..	Carter Oil & Gas Co., well No. 5, NW. ¼, Sec. 16, T. 26 N., R. 6 E. Well completed May 25, 1922	2,819–98	79	53	95 in 12 hours	775	120	2,847–98	.....	21.0	2.712	.....	4
13*B*..	Cosden Oil & Gas Co., well No. 6, NE. ¼, Sec. 6, T. 26 N., R. 6 E. Well completed May 9, 1922	2,836–2,905	69	.....	100	425	140	2,841–2,905	.....	18.4	2.675	.....	5
14*B*..	Sinclair Oil & Gas Co., well No. 4, NW. ¼, Sec. 33, T. 27 N., R. 6 E. Well completed June 15, 1922	2,878–2,938	60	41	150	750	120	2,889–2,938	.....	22.6	2.701	.....	6
15*B*..	Cosden Oil & Gas Co., well No. 11, NW. ¼, Sec. 8, T. 26 N., R. 6 E. Well completed June 2, 1922	2,853–2,919	66	.....	122	460	130	2,859–2,919	.....	17.7 19.7	2.689 2.693	....	7

[1] Well shot March 27, 1922
[2] Well shot August 29, 1921
[3] Well shot May 12, 1922
[4] Well shot May 25, 1922
[5] Well shot May 10, 1922
[6] Well shot June 15, 1922
[7] Well shot June 4, 1922

[1] Well shot March 27, 1922
[2] Well shot August 29, 1921
[3] Well shot May 12, 1922
[4] Well shot May 25, 1922
[5] Well shot May 10, 1922
[6] Well shot June 15, 1922
[7] Well shot June 4, 1922

TABLE I—*Continued*

Reference No.	Location of Well	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Maximum Thickness of Producing Sand (Ft.)	Natural Production (Bbls.)	Greatest Production in 24 Hours (Bbls.)	Size of Shot (Qt.)	Depth to Top and Bottom of Shot (Ft.)	Pore Space, Percentage by Volume	Sp. Gr. of Grains	Percentage of Oil Burned Out	Remarks
	Oil Sands from Burbank Field, Osage County, Oklahoma											
16*B*..	Phillips Petroleum Co., well No. 1, NE. ¼, Sec. 7, T. 26 N., R. 6 E. Well completed April 16, 1922	2,839–2,918	88	69	0	200	130	2,846–2,915	16.4 17.5 17.7	2.701		
17*B*..	Gardner Petroleum Co., well No. 2, SE. ¼, Sec. 1, T. 26 N., R. 5 E. Completed Aug. 23, 1921	2,782–2,860	78	68	200	250	10 20 40 60	2,848–58 2,831–51 2,801–46 2,804–58	21.0 17.3	2.694	14.7	
18*B*..	Simons & Moore, well No. 13, NE. ¼, Sec. 5, T. 26 N., R. 6 E. Well completed Jan. 31, 1922	2,850–2,905	55	55	.....	300	20 20 30	2,875–2,905	18.8 17.1	2.705		[1]
19*B*..	Roxana Petroleum Corp., well No. 4, SE. ¼, Sec. 36, T. 27 N., R. 5 E. Completed June 10, 1921	2,885–2,936	51	40	700	931	60	2,900–2,930	18.8 25.5	2.685	16.8 17.2	[2]
20*B*..	Gypsy Oil Co., well No. 11, NE. ¼, Sec. 31, T. 27 N., R. 6 E. Well completed May 29, 1922	2,900–2,970	70	61	.....	800	140	2,912–70	27.4 18.2 22.9 22.1	2.717	22.9	[3]
21*B*..	Carter Oil & Gas Co., well No. 3, SW. ¼, Sec. 31, T. 27 N., R. 6 E. Well completed Nov. 8, 1921	2,804–70, 2,804–15, gas sand	66	57	.....	120	90	2,870–93	15.0 15.4	2.694	11.9 9.5	[4] [5]
22*B*..	Carter Oil & Gas Co., well No. 6, NE. ¼, Sec. 8, T. 26 N., R. 6 E. Well completed May 16, 1922	2,875–2,942	66	46	.....	297	120	2,894–2,942	17.9 16.4	2.700	4.1	[6]

[1] Well shot February 1, 1922
[2] Well shot September 7, 1921
[3] Well shot May 29, 1922
[4] Well shot November 8, 1921
[5] I.P. from gas sand 10,000 cu.ft.
[6] Well shot May 16, 1922

TABLE I—*Continued*

Reference No.	Location of Well	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Maximum Thickness of Producing Sand	Natural Production (Bbls.)	Greatest Production in 24 Hours (Bbls.)	Size of Shot (Qr.)	Depth to Top and Bottom of Shot (Ft.)	Pore Space, Percentage by Volume	Sp. Gr. of Grains	Percentage of Oil Burned Out	Remarks
	Oil Sands from Burbank Field, Osage County, Oklahoma											
23*B*..	Roxana Petroleum Corp., well No. 1, NE. ¼ Sec. 36, T. 27 N., R. 5 E. Completed May 14, 1920	2,938–3,000	62	51	.....	600	15 20 40 60	2,960–70 2,952–65 2,950–70 2,951–81	23.5 22.2	....	21.2 12.6	1 2 3 4
24*B*..	Cosden Oil & Gas Co., well No. 12, NE. ¼ Sec. 6, T. 26 N., R. 6 E. Well completed March 30, 1922	2,855–2,915	60	55	75	220	125	2,860–2,915	16.7 17.9	....	8.6 9.1	5
25*B*..	Phillips Petroleum Co., well No. 4, NW. ¼ Sec. 30, T. 27 N., R. 6 E.	2,900–2,978	78	20(?)	0	225	195	2,930–78	18.6 21.3 6.1* 7.4*	2.671 2.691 2.658 2.673	8.7 7.3	
26*B*..	Roxana Petroleum Corp., well No. 9, NE. ¼ Sec. 36, T. 27 N., R. 5 E. Completed June 5, 1922	2,935–3,002	67	.....	105	281	60 60	2,967–97 2,937–67	16.0 19.1 21.3	2.678	6.6 6.4 7.5	6 7
27*B*..	Gypsy Oil Co., well No. 6, N.W. ¼ Sec. 5, T. 26 N., R. 6 E. Well completed Jan. 18, 1922	2,845–2,945	100	45	.....	300	110	2,900–2,945	18.2	2.680	16.1	
28*B*..	Kewanee Oil & Gas Co., well No. 8, NE. ¼ Sec. 4, T. 26 N., R. 6 E. Well completed June 1, 1922	2,889–2,936	47	27	.....	310	80	2,906.5–2,938	20.8 19.1 15.9	.... 2.664	6.7 7.3 6.1	8

* These samples were cemented with lime, probably about 15 per cent of lime. This well was thought to be a dry hole until after it was shot. Pay was very thin layer.

1 Well was deepened from 2,965 to 3,001 and shot December 29, 1921
2 January 1, 1922
3 January 4, 1922
4 January 10, 1922
5 Well shot March 30, 1922
6 Well shot June 5, 1922
7 Well shot June 6, 1922
8 Well shot June 2, 1922

29*B*..	Kewanee Oil & Gas Co., well No. 3, NE. ¼, Sec. 4, T. 26 N., R. 6 E. Well completed April 6, 1922	2,849–2,924	75	51	.....	451	140	2,876–2,924	20.5 20.1 20.4	2.700	11.8 11.5 10.7	[1]
30*B*..	Sinclair Oil & Gas Co., well No. 7, NE. ¼, Sec. 32, T. 27 N., R. 6 E. Completed May 27, 1922	2,885–2,944	59	57	.....	600	120	2,890–2,944	21.2 19.1 20.3	2.701	8.3 17.3 13.0	[2]
31*B*..	Prairie Oil & Gas Co., well No. 2, SW. ¼, Sec. 33, T. 27 N., R. 6 E. Completed May 12, 1922	2,921–3,005	84	55	75	590	85	2,958–98	20.9 22.6	2.678	13.0 12.8	
32*B*..	Producers & Refiners Corp., well No. 8, NW. ¼, Sec. 31, T. 27 N., R. 6 E. Well completed Dec. 6, 1921	2,892–2,973	81	.....	800	1,280	210	2,895–2,977	28.0 28.0	....	12.2 13.8	[3]

[1] Well shot April 11, 1922
[2] Well shot May 27, 1922
[3] The greatest production, 1,280 bbls., was recorded while the tools were still in the well

TABLE I—*Continued*

Reference No.	Location of Well	Field or Pool	Name of Sand	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Natural Production (Bbls.)	Initial Production (Bbls.)	Depth to Top and Bottom of Shot (Ft.)	Size of Shot (Qt.)	Samples, How Collected	Pore Space Percentage by Volume	Total Wt. of Sple. (Gm.)	Sp. Gr. of Grains	Percentage of Oil Burned Out	Sp. Gr. of Oil	Remarks
	Oil and Gas Sands from Texas															
32..	Magnolia Petroleum Co., Joe Duke well No. 1, near Desdemona, Comanche County	.....	.....	2,654–?	.....	Came in 500, later 6,000		.....	.....	Drill cuttings	17.1	1.156	2.642	.....	.....	[a]
33..	Humble Oil & Refining Co., Webb well No. 1, 5 mi. south of Ranger, Eastland County. Completed Dec. 27, 1919	.....	McClesky	3,135–42	18 ± in the lime	.....	400	.....	.....	Drill cuttings	6.6 8.5	5.944 2.964	2.662	.....	.....	
34..	Humble Oil & Refining Co., Dick Gray well No. 1, ½ mi. SW. of Desdemona, Eastland County	Desdemona	.....	2,637–?	.....	.....	200	2,639–43	.....	Shot out	15.6	4.014	2.669	.....	.....	
35..	Skelly and Sankey, Hogg well No. 1, Comanche County	.....	.....	2,680–2,707	.....	.....	1,150	.....	.....	Drill cuttings	14.6	4.568	2.665	.....	.....	
36..	Sammies Oil Co., Thorpe well No. 1, 1½ mi. SW. of Gunsight, Stephens County	.....	.....	Production at 1,724	.....	.....	100	.....	.....	Shot out	20.7	4.170	2.660	.....	.....	
37..	Humble Oil & Refining Co., Dick Gray lease, 1 mi. W. of Desdemona, Eastland County	.....	.....	2,630+	.....	.....	.....	.....	.....	.....	18.2	7.918	2.659	.....	.....	
38..	Humble Oil & Gas Co., Leonard and Gilman Ward well No. 1, Eastland County	.....	.....	Gas sand, 3,312–?	.....	.....	3,000,000 cu. ft.	.....	.....	.....	19.3	1.962	2.68	.....	.....	

[a] Sample from top of sand

39..	Sinclair Consolidated Oil & Gas Co., Vaughn well No. 3, near Caddo, Stephens County	.....	Blacklime	.....	.....	.....	750	3,334–3,423	.....	Shot out	5.5 7.8 3.7 6.1	8.530 13.948	.....	.....	.....	
40..	Mid-Kansas Oil & Gas Co., Graham well No. 1, 1½ mi. West of Ivan, Stephens County	.....	.....	3,252–?	.....	.....	5,000,000 cu.ft., 10	.....	.....	Drill cuttings	19.4	1.103	2.706	.....	.....	[1]
41..	Sinclair Consolidated Oil & Gas Co., Holt well No. 1, 25 mi. N.E. of Ranger, Palo Pinto County	.....	.....	.....	.....	50	150	.....	.....	Drill cuttings	11.0	1.030	2.599	.....	.....	[2]
119..	Humble Oil & Refining Co., Musick well No. 4, Burkburnett, Wichita County	Townsite	.....	1,616–60	44	.....	Small producer	.....	.....	Shot out	24.6	2.785	2.652	.....	.....	
120..	Humble Oil & Refining Co., Brannon well No. 4, Burkburnett, Wichita County, NW. extension	NW. extension	.....	1,693–1,709	.....	.....	500	.....	.....	.....	22.9 24.3	2.654 9.965	2.652	.....	.....	
99..	Humble Oil & Refining Co., Maxey well B1, Burkburnett, Wichita County	N.W. extension	.....	.....	.....	.....	.....	.....	.....	.....	28.9 28.0	4.562 5.274	2.662	.....	.....	
46..	Sinclair Consolidated Oil & Gas Co., Satterfield well No. 3, Ranger, Eastland County	.....	Blacklime	.....	.....	.....	.....	.....	.....	Bailed out	4.5	4.740	2.662	.....	.....	[3]
126..	T. Morton well No. 1, H. & T. C. R.R. Survey, 10 mi. west of Ranger, Eastland County	.....	Caddo lime	2,913–?	.....	.....	.....	.....	.....	Shot out	4.4 4.2	11.266 7.062	2.693	.....	.....	
97..	Gulf Production Co., S. B. Burnett well No. 1, Carson County	.....	.....	2,391–2,410	.....	.....	70,000,000 cu.ft. gas	.....	.....	.....	16.8	5.592	2.836	.....	.....	[4]
		.....	Blacklime	.....	.....	.....	.....	.....	.....	.....	3.4	34.092	.....	.....	.....	[5]
	Tolle well No. 2	.....	Blacklime	.....	.....	.....	.....	.....	.....	.....	3.4	4.847	.....	.....	.....	[6]
66..	Amarillo Oil Co., Birnes well No. 1, 20 mi. NW. of Amarillo, Potter County	.....	.....	1,900–1,960	60	.....	18,000,000 cu.ft. gas	.....	.....	Blown out by gas	7.3	1.025	.....	.....	.....	

[1] Drill cuttings from top of sand
[2] Drill cuttings from 4,104–8 ft.
[3] None of the samples from the Black or Caddo lime, which had very low percentages of porosity, had openings sufficiently large for the production of oil. No oil was found in any of the samples.
[4] Mainly lime, pores quite large, some over 1 mm. in diamater
[5] Not a trace of oil found in sample
[6] Not a trace of oil found in sample

TABLE I—*Continued*

Reference No.	Location of Well	Field or Pool	Name of Sand	Depth to Top and Bottom of Sand (Ft.)	Thickness of Sand (Ft.)	Natural Production (Bbls.)	Initial Production (Bbls.)	Depth to Top and Bottom of Shot (Ft.)	Size of Shot (Qt.)	Samples, How Collected	Pore Space, Percentage by Volume	Total Wt. of Sple. (Gm.)	Sp. Gr. of Grains	Percentage of Oil Lubned Out	Sp. Gr. of Oil	Remarks
	Gas Sands from Louisiana															
136..	Well in Monroe-Louisiana gas field	Monroe gas	"Gas sand"	.....	.....	.....	.....	.....	.....	.....	31.6 31.0	3.474 3.077	2.727 2.728	.....	.....	
137..	Well in Monroe-Louisiana gas field	Monroe gas	"Gas sand"	.....	.....	.....	35,000,000 R.P. 1,100 lb.	.....	.....	.....	14.3	7.045	2.678	.....	.....	[1]
138..	LaDel Oil Co., well No. 1, SE. ¼, Sec. 16, T. 19 N., R. 5 E., Ouachita Parish. Completed May 12, 1920	Monroe gas	"Gas sand"	2,150–?	25	.....	17,000,000 I.R.P. 1,100 lb.	.....	.....	.....	22.0	6.469	2.734	.....	.....	
139..	Well in Monroe-Louisiana gas field	Monroe gas	"Gas sand"	.....	.....	.....	.....	.....	.....	.....	40.3	1.981	.....	.....	.....	
154..	From well in Sec. 14, T. 19 N., R. 4 E., Ouachita Parish	.....	"Gas sand"	.....	.....	.....	.....	.....	.....	.....	41.3	11.273	2.729	.....	.....	
156..	From well in northern Louisiana	.....	"Gas sand"	.....	.....	.....	.....	.....	.....	.....	27.9	9.520	.....	.....	.....	
	Oil and Other Horizons from California															
145..	Surface of Rogers Dry Lake, Sec. 25, T. 9 N., R. 9 W., Kern County	.....	Outcrop	.....	.....	.....	.....	.....	.....	.....	38.3 37.8	8.431 9.380	2.713	.....	.....	
146..	Upper clay member above gravel in bank of Mohave River, Sec. 12, T. 9 N., R. 1 E., south of Yermo	.....	Outcrop	.....	.....	.....	.....	.....	.....	.....	43.1	12.661	2.730	.....	.....	

[1] Sample consisted mainly of lime and shell fossils

[1] Sample consisted mainly of lime and shell fossils

147..	Lower clay member beneath gravel in bank of Mohave River, Sec. 12, T. 9 N., R 1 E., south of Yermo	.....	Outcrop	.....	.....	.....	.....	.....	.....	.....	35.7	9.686	2.698	.....	.....	
	Well in SW. corner Sec. 18, T. 26 S., R. 21 E., Lost Hills, Kern County	.....	.....	.....	.....	.....	.....	.....	.....	.....	18.6 22.4	7.580 17.155	2.729 2.720	.....	.....	[1]
141..	From thin stratum in Salinas shale, of Monterey group, dipping 55° S., west of Goleta Landing, Santa Barbara County	.....	.....	.....	.....	.....	.....	.....	.....	Outcrop	33.3	7.647	2.672	.....	.....	
142C	A. I. Clark lease, well No. 1	Santa Fe Springs	.....	3,965–?	.....	.....	.....	.....	.....	.....	31.0	.....	.....	.....	.....	[2]

[1] Well producing heavy oil

[2] The core sample consisted of almost an unconsolidated sand

A greater part of the work was a study of the Newcastle and the "First Wall Creek" sands. Though the First Wall Creek sand is fine grained, the Newcastle sand is much finer grained, with an average diameter of grain of about 0.1 mm.

The cumulative distribution of diameters of grains of six samples of the First Wall Creek sand from four wells in the Big Muddy oil field is given in Figure 4, and the percentage distribution of diameters of grains is given in Table II. The average diameter

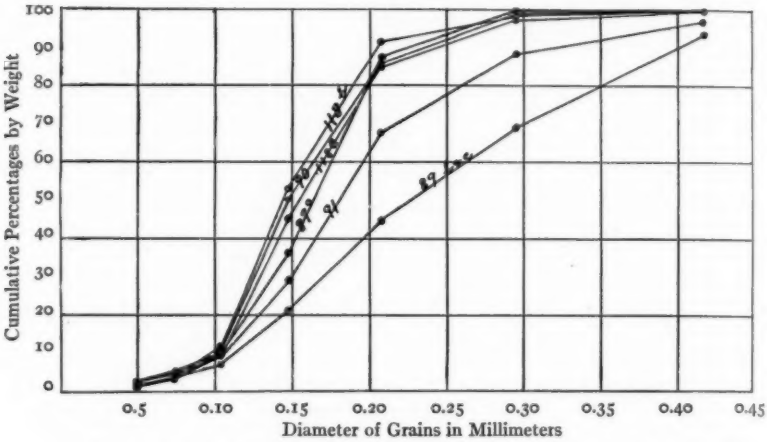


FIG. 4.—Cumulative percentage distribution of diameter of grains of six samples of the First Wall Creek sand from four wells, Big Muddy Field, Wyoming. Numbers on curves refer to reference numbers in tables.

of grains is about 0.17 mm., with less than 10 per cent of the grains under 0.1 mm. in diameter.

The curves in Figure 4 show a very uniform decrease in diameter of grains for the samples, especially for diameters under 0.1 mm.

The pore space of the samples of the First Wall Creek sand from producing wells varied from 17 to 23 per cent. The pore space of samples from outcrops of this sand (known as the Wall Creek sandstone member of the Frontier formation)[1] varied from about 8 to 26 per cent.

[1] Percentage of pore space of samples from the outcrop of the "First Wall Creek" sand are given by the writer in determination of pore space of oil and gas sands, *Bull. Amer. Inst. of Min. and Met. Eng.* (April, 1920), p. 19, Table VII.

The pore space of samples from both outcrops and producing wells of the Newcastle sand in the Osage oil field was studied more in detail than the First Wall Creek sand. The porosity of samples of the Newcastle sand from three wells, including the diamond-core-drilled samples, varied from 12.5 to 26 per cent. The pore space of samples from outcrops of the Newcastle sand near Osage, Newcastle, and Moorcraft varied from 9 to 25 per cent. If the two lowest percentages are omitted, the percentage of pore space of the samples from the outcrops would vary between 19 and 25, and the pore spaces for samples from the wells would vary between 15 and 26 per cent. The comparison of the percentages of pore space of samples from outcrops of the Newcastle and First Wall Creek sands with samples of the same sand from producing wells does not indicate that the porosity of a sand in a producing field is greater than the porosity of this sand at its outcrop, as has been suggested by some geologists,[1] but indicates that the porosities have similar ranges.

FIG. 5.—Diamond-drilled core of the Newcastle sand, showing alternating shale and sand. Natural size.

Figure 5 shows alternating shale and sand in a diamond-drilled core of the Newcastle sand. The dark-colored portion is shale,

[1] C. W. Washburne, "Oil-Field Brines," *Trans. Amer. Inst. of Min. and Met. Eng.*, Vol. 65 (1921), p. 276, and "Discussion of Determination of Pore Space of Oil and Gas Sands," *ibid.*, p. 497.

while the light-colored part is sand. Oil from the fine sand partings in shale often seems to come from the shale itself, as it is difficult to recognize the fine sand in wet cuttings of shale and fine sand.

Mr. A. J. Collier collected the samples from the core-drilled well, co-operated with the writer, and gave many valuable suggestions in the field work in Wyoming.

FIG. 6.—Sample of Bartlesville sand showing shale *A*, together with hard sandstone *A–B*, which could have served as cap rock and very probably did. Producing sand *B–C*. Scale shows centimeters.

OIL SANDS OF OKLAHOMA

A general field study was made of some of the oil sands in Oklahoma during December, 1919, and a special field study was made of the Hickman sand, Burbank field, Oklahoma, during May and June, 1922. Samples of the producing oil sand were collected from 135 wells, and 155 determinations of pore space were made on samples from 80 of the wells.

The percentage of pore space, specific gravity of grains, and data on shooting of wells, thickness of sand, and production of wells, are given in Table I. The cumulative percentage distribution of diameters of grains by weight is given in Figures 7, 8, and 9, and the

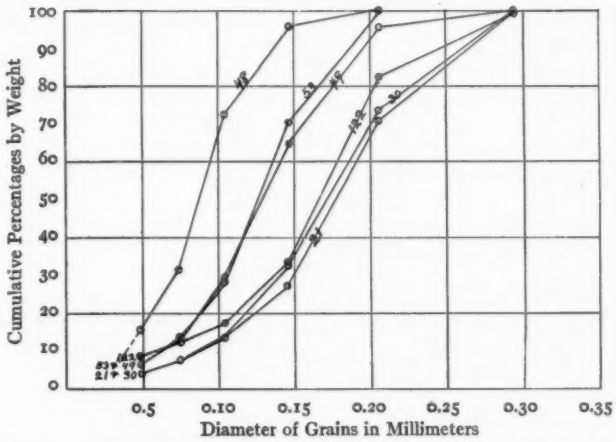


FIG. 7.—Cumulative percentage distribution of diameter of grains of six samples of Bartlesville sand from six wells, Oklahoma. Numbers on curves refer to reference numbers in tables.

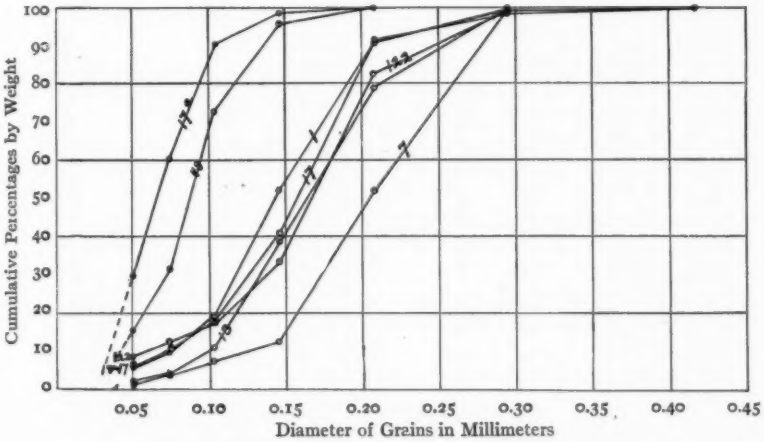


FIG. 8.—Cumulative percentage distribution of diameter of grains of seven samples of Bartlesville sand from seven wells, Oklahoma. Numbers on curves refer to reference numbers in tables.

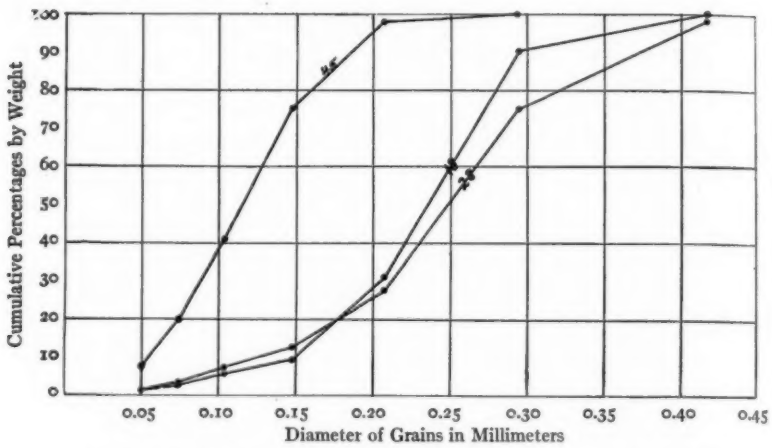


FIG. 9.—Cumulative percentage distribution of diameter of grains of three samples of oil sands, Layton, Bartlesville, and Wayside sands. Numbers on curves refer to reference numbers in tables.

percentage distribution of diameters of grains by weight is given in Table II.

BARTLESVILLE SAND

Drill cuttings were collected from top to bottom of the Bartlesville sand from three producing wells, and 25 to 50 chunk samples of the Bartlesville sand were collected from some wells after the fragments had been shot out, on the ground or by means of the bailer. The producing part of the Bartlesville sand varied in pore space from 12 to 39 per cent. The grains of the samples (reference No. 19) which had pore spaces of 38 and 39 per cent were so fine grained that all the grains would have passed through the 300-mesh sieve (less than 0.05 mm. in diameter). With the exception of the samples from this well, the sizes and distribution of diameters of grains are fairly uniform for the better producing part of the Bartlesville sand. Then both total production and rate of production of oil from the Bartlesville sand would depend largely upon the percentage of pore space and thickness of the pay sand for any unit of area of the producing part of the sand. The data on percentage of pore space

TABLE II

PERCENTAGE DISTRIBUTION OF DIAMETERS OF GRAINS OF OIL SANDS

Samples of the "First Wall Creek Sand" from Four Wells in the Big Muddy Field, Wyoming

DIAMETERS FROM	REFERENCE NUMBERS						
	89*a*	89*bc*	90	91	118*a*	118*b*	118*c*
0.417–0.833 mm., per cent	.....	6.5	.....	3.4	.....	0.1	0.2
0.295–0.417 mm., per cent	0.5	24.7	1.2	8.2	1.1	1.6	2.7
0.208–0.295 mm., per cent	12.3	24.3	13.2	21.0	5.4	7.1	12.3
0.147–0.208 mm., per cent	51.2	23.5	35.6	38.4	35.9	38.5	39.8
0.104–0.147 mm., per cent	26.4	14.2	39.4	20.3	42.1	41.1	35.8
0.074–0.104 mm., per cent	4.4	3.2	7.5	4.2	11.2	8.3	5.6
0.05 –0.074 mm., per cent	2.7	1.6	1.9	1.9	2.9	1.3	1.8
0.00 –0.05 mm., per cent	2.5	2.0	1.2	2.6	1.4	2.0	1.8
Total per cent	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Samples of Bartlesville Sand from Ten Wells, Oklahoma

DIAMETERS FROM	REFERENCE NUMBERS										
	1	7	13	17	17*a*	21	45	48	49	53	122
0.295–0.417 mm., per cent	1.5	1.1	0.2	.....	.....	0.2	.....	.....	.....	.....	0.9
0.208–0.295 mm., per cent	7.1	46.9	21.0	0.4	.....	29.0	2.1	.....	4.7	0.2	16.6
0.147–0.208 mm., per cent	39.4	39.8	40.2	49.8	1.4	43.5	22.8	4.3	30.8	29.6	48.2
0.104–0.147 mm., per cent	32.7	5.0	27.8	22.8	8.4	13.6	34.1	23.3	35.1	42.0	16.8
0.074–0.104 mm., per cent	9.5	3.6	6.8	7.3	30.0	6.2	21.2	41.2	16.7	15.1	5.1
0.05 –0.074 mm., per cent	4.2	1.8	1.7	4.5	30.3	3.4	11.9	15.7	6.1	6.4	3.7
0.00 –0.05 mm., per cent	5.6	1.8	2.3	6.2	29.9	4.1	7.9	15.5	6.6	6.7	8.7
Total per cent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

One Sample Each from Glenn, Layton, and Wayside(?) Sands, Oklahoma

DIAMETERS FROM	REFERENCE NUMBERS		
	30	18	28
0.417–0.833 mm., per cent	.....	.....	1.8
0.295–0.417 mm., per cent	.....	10.0	23.2
0.208–0.295 mm., per cent	26.3	58.9	47.4
0.147–0.208 mm., per cent	41.0	21.9	15.0
0.104–0.147 mm., per cent	19.2	3.8	5.5
0.074–0.104 mm., per cent	6.0	2.0	3.7
0.05 –0.074 mm., per cent	3.3	1.4	2.0
0.00 –0.05 mm., per cent	4.2	1.1	1.4
Total per cent	100.0	100.0	100.0

Samples of the Hickman Sand from Six Wells in the Burbank Field, Osage County, Oklahoma

DIAMETERS FROM	REFERENCE NUMBERS							
	1–Bb	2–Ba	3–Be	3–Ba	5–Be	20–Bc	30–Ba	30–Bc
0.295–0.417 mm., per cent	.....	.....	.....	.....	.....	1.7	0.1	.....
0.208–0.295 mm., per cent	0.3	.....	0.4	1.0	28.5	14.3	49.3	40.8
0.147–0.208 mm., per cent	18.2	.....	34.5	60.5	58.5	55.3	33.1	42.1
0.104–0.147 mm., per cent	43.5	6.1	39.0	22.4	6.3	17.2	7.7	7.8
0.074–0.104 mm., per cent	19.9	32.4	10.8	6.3	2.7	5.8	4.5	4.4
0.05 –0.074 mm., per cent	8.7	32.4	7.6	3.9	2.1	4.0	2.7	2.4
0.00 –0.05 mm., per cent	9.4	29.1	7.7	5.9	2.1	1.7	2.6	2.5
Total per cent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE II—*Continued*

Samples of Oil Sands from Three Wells in the Northwest Extension of the Burkburnett Field, Texas

Diameters From	Reference Numbers		
	99	119	120
0.417–0.833 mm., per cent	5.8	0.4	4.3
0.295–0.417 mm., per cent	20.3	26.9	27.5
0.208–0.295 mm., per cent	45.2	39.5	38.8
0.147–0.208 mm., per cent	22.4	25.0	20.5
0.104–0.147 mm., per cent	2.8	3.5	6.2
0.074–0.104 mm., per cent	1.7	1.5	2.0
0.05 –0.074 mm., per cent	0.9	0.8	0.4
0.00 –0.05 mm., per cent	0.9	0.4	0.4
Total per cent	100.0	100.0	100.1

indicate that the lower limit of porosity for commercial production of the Bartlesville sand is between 12 and 14 per cent.

THE HICKMAN SAND, BURBANK FIELD

The method described in this paper was closely followed in the examination and collection of representative samples from the different texture types of oil sand from wells in the Burbank field. Over 2,000 chunk samples were collected from 89 wells, and drill cuttings were collected from top to bottom of the producing sand in 12 wells. The wells were shot with nitroglycerine at least once, and sometimes a single well was shot as many as six times.

Fragment samples of oil sand were best collected at the time of cleaning out the well after the shot, as cavings from the best pay of large producing wells usually supplied chunks which were sometimes obtained by the bailer or sand pump. Sometimes from a single well 100 to 150 chunk samples were collected from several hundred pieces examined. Fragments from the harder pay were often shot out, but chunks of the best pay were not so often shot out of a well, as they were usually completely unconsolidated by the force bringing them to the surface.

Determinations of pore space were made on 84 samples representing the different texture types of the producing sand in 32 wells. The percentage of pore space, specific gravity of grains, and data on shooting, thickness of producing sand, and production of wells are given in Table I. Samples of oil-bearing sand from commercially producing wells[1] varied from about 13 to 33 per cent in pore space.

[1] Commercially producing wells were those which made an initial production of 25 barrels or more in 24 hours.

The grains of the best producing part of the Hickman sand were so loosely held together that fragments of the sand could easily be broken into their separate grains between the thumb and fingers.

The cumulative percentage distribution of diameters of grains is given in Figure 10. The percentage distribution of diameters of grains is given in Table II. (The small letters refer to the samples of oil sand used; the figures and large letters refer to reference numbers in Table I.)

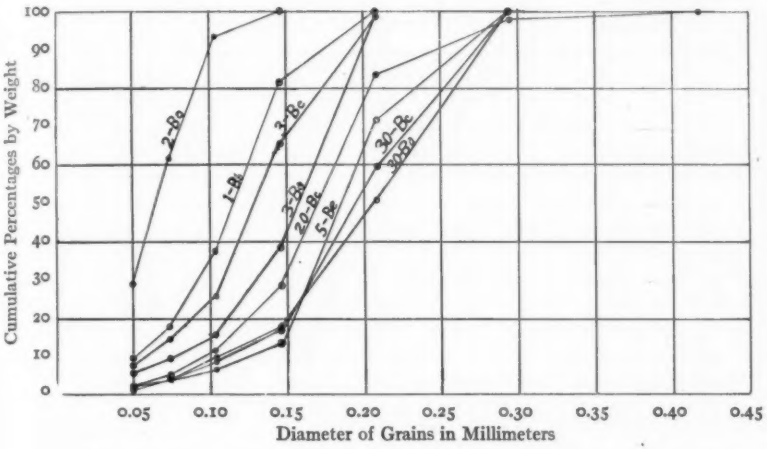


FIG. 10.—Cumulative percentage distribution of diameter of grains of eight samples of the Hickman sand from six wells, Burbank Field, Oklahoma. Numbers on curves refer to reference numbers in tables. The small letters refer to the samples of oil sand used.

The distribution of diameters of grains of the samples from the better producing part of the Hickman sand are quite uniform. This uniformity of the size of grains is shown by the curves *20Bc*, *5Be*, *30Ba*, and *30Bc*, in Figure 10. As the eastern edge of the field is approached, the diameter of grain of the producing sand becomes less until the sand finally merges into sandy shale. Curve *2Ba* illustrates determinations on samples of the best producing part of the Hickman sand in a well on the eastern edge of the field. The well from which these samples were obtained was almost a

dry hole. Curve *1Bb* shows diameters of grains from samples of the best producing part of the Hickman sand in a well one location west of this well. Curves *3Be* and *3Ba* show diameters of grains of samples of oil sand obtained from a well on the western side of the field.

Figure 11 is a production-porosity curve of the Hickman sand. The porosity plotted is generally the average of several determina-

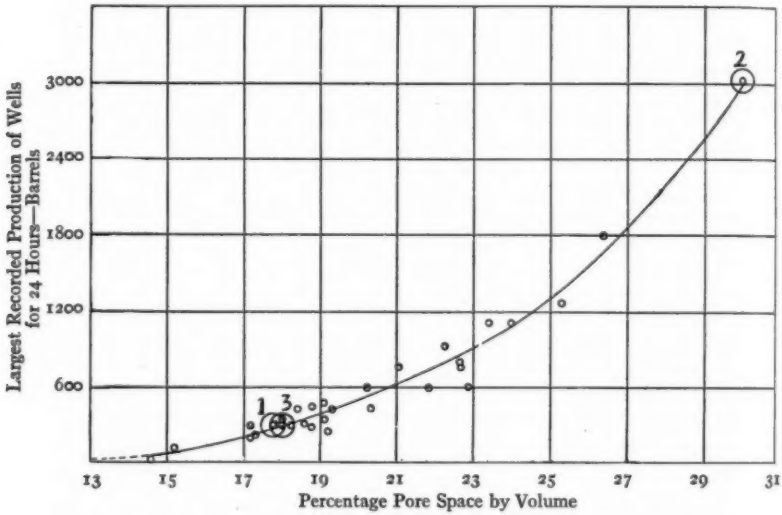


FIG. 11.—Production-porosity curve of the producing sand of the Burbank Field, Osage County, Oklahoma.

tions of pore space of samples taken from one well. For this determination representative samples of oil sand typifying the different kinds of texture were selected. The thirty percentages of porosity plotted represent an equal number of wells distributed fairly equitably over the Burbank field as developed in June, 1922. All the wells except two given in Table I are represented on the curve. The two wells not represented on the curve are *25B* and *32B* in Table I. The average pore space of 28 per cent for sand from well *32B* was not plotted on the production-porosity curve, as it was known that

the flow of this well was partly obstructed by the tools fastened in the casing, when its maximum production of 1,280 barrels was recorded. According to the curve, this well should have produced about 2,000 barrels in 24 hours as its maximum.

A large number of the samples of the Hickman sand from well No. 25*B* were cemented with about 19 per cent calcium carbonate. Microscopic examination of samples from about 90 wells and hydrochloric acid tests on samples from about 40 of these failed to show another well where samples of the producing member were appreciably cemented with lime. This well apparently struck a small, tightly cemented area. The limited extent of the cementation is shown by good yields of wells on three sides of this well. Furthermore, the samples examined from these other 3 wells contained no noticeable quantity of lime. The results of chemical analysis on samples of the producing sand from 6 wells are given on page 773.

Figure 12 is a geological structure map with contours drawn on top of the Hickman sand, Burbank field, made available through the courtesy of G. S. Rollin, of the Roxana Petroleum Corporation. The locations of the wells, given in Table I, are shown in relation to geological structure on this map.

John G. Douglas assisted in making the determinations of pore space on samples of oil sand from the Burbank field and K. C. Heald correlated some of the sands of Oklahoma.

J. George Wright and William Ash Waid, Osage Indian Agency, Pawhuska, Oklahoma, furnished a great deal of the field data for the Burbank field.

CONCLUSIONS

The production-porosity curve of the Burbank field shows evidence not only of an interesting relation between the average percentage of pore space of the producing sand and the greatest production for 24 hours of the wells, but also indicates that in the Burbank field the greatest rate of production will be in areas of largest average percentage of pore space regardless of relation to geologic structures. The curve indicates also that an average pore space of about 13 per cent is the lower limit for commercial production of the producing sand in the Burbank field.

The close relation between average percentage of pore space and maximum production for 24 hours of the wells is largely due to the

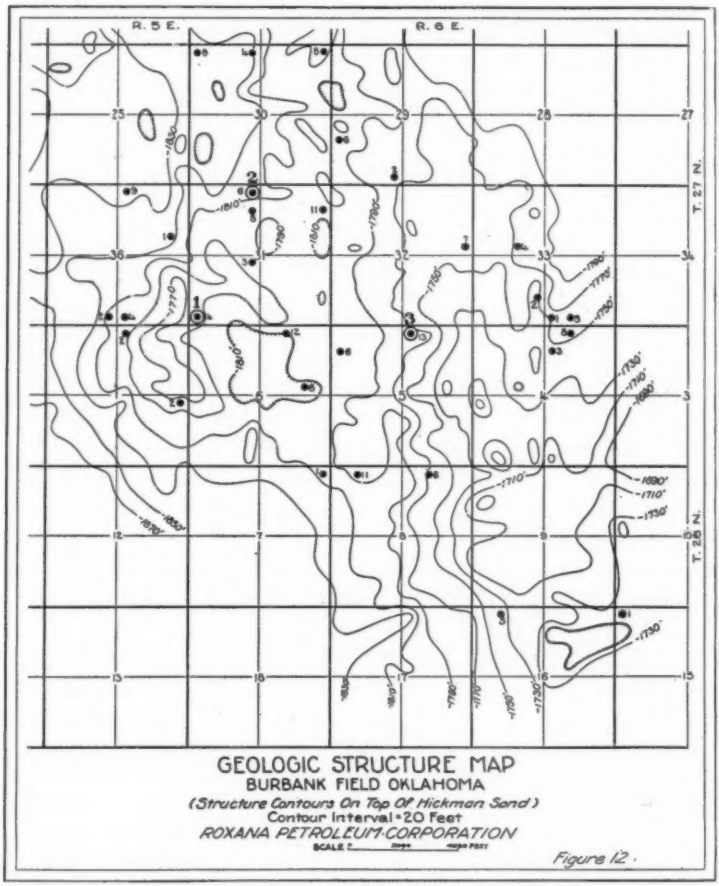


FIG. 12.—Geological structure map, Burbank field

small ranges of variations in most of the other physical factors, as structure, size of grain, pressure and temperature, specific gravity, and viscosity of the oil.

General conclusions should not be drawn upon relations of physical properties of an oil sand to production of oil until an extensive field and laboratory examination has been made of representative samples of the producing sand collected from a number of wells distributed fairly equitably over the field. Continuous cores, yielding samples representing the different texture types from top to bottom of the producing sand, would of course be the best.

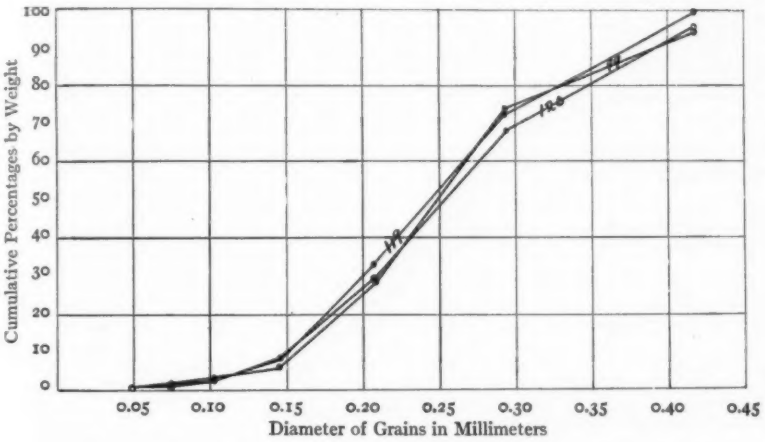


FIG. 13.—Cumulative percentage distribution of diameter of grains of three samples from Burkburnett, northwest extension, Texas. Numbers on curves refer to reference numbers in tables.

Work already done on the uniformity of size of grains of the Bradford sand, First Wall Creek sand, Bartlesville sand, and the producing oil sand of the northwest extension of the Burkburnett field (Fig. 13) indicates that a production-porosity curve might be derived for any one of these oil sands in a single field or pool.

With the exception of samples from one well, the size and distribution of sizes of grains are fairly uniform for the better producing part of the Bartlesville sand. Then both total production and rate of production of oil from the Bartlesville sand would depend largely upon the percentage of pore space and thickness of the pay sand for any unit of area of the producing part of the sand. The

data on percentage of pore space indicates that the lower limit of porosity for commercial production of the Bartlesville sand is about 12 per cent.

The occurrence of lime in a quartz oil sand may or may not decrease its porosity. The mode of occurrence of lime in quartz oil sands is very important in determining its effect on porosity.

The writer is studying the mode of occurrence of cementing material in oil sands as determined by porosity and revealed by microphotographs of thin sections of these sands. A discussion on the application of the production-porosity curve of the Burbank field to production of oil is now being prepared for publication.

The percentages of total pore space and curves on sizes of grains of oil sands indicate that sizes of grains of an oil sand of one field cannot be compared with the sizes of grains of an oil sand of another field for determinations of porosity.

SUMMARY OF RANGES OF POROSITY OF OIL AND GAS SANDS

The ranges of variations in pore space of oil sands are generally not the same in the different fields of the United States.

The ranges of porosity of the samples from the different fields and sands are as follows:

	Per cent
Pay sands from Pennsylvania	7 –19
Bradford oil sand, Pennsylvania	15 –19
"First Wall Creek oil sand," Wyoming	17 –26*
Newcastle oil sand, Wyoming	12.5–26
Bartlesville oil sand, Oklahoma	12 –39
Hickman oil sand, Burbank field, Oklahoma	13 –33
Pay sands from northern Texas	7 –29
Pay sand from Gulf Coast, Texas	31 –34.5
Gas sands from Louisiana	14 –41
Core sample from Santa Fe Springs field, California	31

Ranges of percentage of pore space of samples from outcrops and from wells in producing fields of the "First Wall Creek" and Newcastle oil sands are similar.

* The percentages of pore space of samples of the "First Wall Creek oil sand," which had porosities of 26 per cent, were published in a previous article by the writer, "Determination of Pore Space of Oil and Gas Sands," *Bull. Amer. Inst. of Min. and Met. Eng.* (April, 1920), p. 19.

CHEMICAL ANALYSIS OF SAMPLES OF THE PRODUCING FORMATION FROM WELLS IN THE BURBANK FIELD, OKLAHOMA

Hydrochloric acid tests were made on samples of the producing formation from about forty wells, and only in one well was an appreciable quantity of the cementing material of the sand found to be calcium carbonate.

Samples of the oil sand from six wells were submitted to Mr. E. P. Henderson, of the Chemical Laboratory, for analysis. The following report is the result of his analysis:

WAITE PHILLIPS CO., WELL NO. 1 S.E. ¼, Sec. 33, T. 27 N., R. 6 E., Okla.		SINCLAIR OIL & GAS CO., WELL NO. 2 SW. ¼, Sec. 36, T. 27 N., R. 5 E., Okla.	
Insoluble	83.52	Insoluble	83.90
R_2O_3	9.45	R_2O_3	7.12
CaO	0.15	CaO	0.45
MgO	0.88	MgO	0.57
	94.00		92.04

CARTER OIL & GAS CO., WELL NO. 4 S.W. ¼, Sec. 31, T. 27 N., R. 6 E., Okla.		WAITE PHILLIPS CO., WELL NO. 5 SE. ¼, Sec. 33, T. 27 N., R. 6 E., Okla.	
Insoluble	85.82	Insoluble	86.65
R_2O_3	4.67	R_2O_3	7.77
CaO	0.26	CaO	0.10
MgO	0.53	MgO	0.66
	91.28		95.18

PHILLIPS PET. CO., WELL NO. 4 NW. ¼, Sec. 30, T. 27 N., R. 6 E., Okla.		PRODUCERS AND REFINERS CORP., WELL NO. 6 NW. ¼, Sec. 31, T. 27 N., R. 6 E., Okla	
Insoluble	72.95	Insoluble	82.95
R_2O_3	3.20	R_2O_3	7.58
CaO	10.70	MgO	0.19
MgO	0.75	CO_2	0.39
CO_2	8.38		91.11
	95.98		

Material was crushed to a sand, but was not ground, and a well-sampled portion was weighed out for analysis. Two-gram samples were taken in each case.

The organic matter was dissolved out of the sand by treating it with carbon tetrachloride until a clear filtrate resulted. This was followed by a similar treatment with ether, which removed the last traces of organic matter and water.

The remaining insoluble portion was boiled with 1–1 hydrochloric acid for 30 minutes and the solution decanted through a filter. The residue was again boiled 5 minutes to test the completeness of hydrochloric acid treatment. The second boiling with hydrochloric acid seldom showed any discoloration. This was decanted through the above-mentioned filter and the residue washed on the paper with hot water until free from chlorides and burned in a weighed platinum crucible. The resulting weight is called insoluble.

The R_2O_3 group was precipitated in the usual manner after the addition of enough bromine water to oxidize the ferrous iron to the ferric condition. It was noted that most of the iron was present as ferrous iron. The R_2O_3 group is practically pure Fe_2O_3.

The carbon dioxide (CO_2) in the Phillips Petroleum Company well No. 4 was calculated from the CaO and not determined direct.

THE LULING OIL FIELD IN CALDWELL COUNTY, TEXAS[1]

E. H. SELLARDS
University of Texas, Austin

INTRODUCTION

The Luling oil field in Caldwell County extends from near San Marcos River at the south line of the county in a northeasterly direction a distance of about $3\frac{1}{2}$ miles, terminating near Joliet. The northernmost wells are about 8 miles south of Lockhart, while the southern part of the field is within about 5 miles of Luling. The field is 40 miles southeast of Austin, 50 miles northeast of San Antonio, and 150 miles west of Houston. It is reached by the Southern Pacific Railway from Houston or San Antonio.

HISTORY OF DEVELOPMENT

Test wells on the Cartwright property in the vicinity of the Luling field were begun by the United North and South Oil Company as early as March, 1921. Previous to this time drilling had been carried on by the same interests on the Thompson lease under the name of the Texas Southern Oil and Lease Syndicate. On the Cartwright property four wells were drilled during 1921 and 1922. On June 19, 1922, drilling was begun by the same company on the Rios property, located about $1\frac{1}{4}$ miles northeast of the Cartwright wells. The Rios well, completed August 8, 1922, was the first producer in the field. Up to February 1, 1924, about 100 producing wells had been obtained in this field, extending northeasterly in a narrow belt for $3\frac{1}{2}$ miles.[2]

The field was located upon geologic advice. The fault which determines production was first observed, so far as the writer is

[1] Published by permission of the director of the Bureau of Economic Geology of the University of Texas.

[2] Recently the field has been extended into Guadalupe County by the completion, on December 28, 1923, of a well on the Leopoldo Marines lease of the United North and South Oil Company. The Guadalupe County extension of the field is not included in this paper. (Manuscript of this paper submitted February, 1924.)

aware, by E. V. Woolsey, by whom also the first test wells were located. Subsequently, additional investigations were made by G. C. Matson, David Donoghue, and E. W. Brucks.

THE PRODUCING HORIZON

Production in the Luling field is from the Edwards formation. This fact has been determined from fossils contained in the numerous cores obtained from the pay horizons. Edwards fossils have been found immediately upon entering the pay. On the other hand, characteristic Georgetown fossils have been found at a slightly higher level. The producing horizon is therefore placed as within the Edwards, those horizons now producing being near the top of the formation.

A few of the wells have obtained production immediately upon entering the Edwards formation, while others obtained moderate production from 18 to 27 feet from the top. At the depths of 29–37 feet in the Edwards is a horizon in which the greatest number of wells have terminated and from which probably the largest initial production has been obtained. Again, from 42 to 46 feet in the Edwards very considerable production is secured. A few wells have continued below this depth, some production having been obtained from as deep as 77 feet in the formation. The known porous character of the rock indicates a possibility of production at still greater depths.[1]

SURFACE GEOLOGY

The surface rocks in the Luling field are of Eocene age and belong to the Wilcox formation. On the upthrow side of the fault the Wilcox is thin, in places possibly not exceeding 50 or 100 feet in thickness. Within the Wilcox of this area two units or members may be recognized. The lower or basal Wilcox member includes chiefly sandy, micaceous shales, and yellow, often banded bowlder-like sandy limestone concretions. These limestone concretions vary in size and shape, the larger ones being flattened. The weath-

[1] The following publications include references to the producing horizon in this field: E. H. Sellards, "The Producing Horizon in the Rios Well in Caldwell County," *Univ. Texas Bull. 2239*, November, 1922; and Wallace E. Pratt, "Oil at Luling, Caldwell County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, March-April, 1923.

ered surface is prevailingly yellow, although the freshly broken rock is often dark gray and more or less banded, depending upon the degree of weathering. Fossils are not infrequently present in this rock. The sandy, micaceous shales of this member of the Wilcox also occasionally contain fossils, preserved for the most part as casts. The thickness of this phase of the Wilcox is undetermined. It may approximate 100 feet, although no actual measurement has been obtained.

This phase of the Wilcox, micaceous shales and yellow-rock bowlders, is found at the surface in the Luling field on the upthrow side of the fault from San Marcos River northeast to somewhat west of Joliet. The same phase of the formation is also found forming a belt 1 or 2 miles in width adjacent to the Midway 3 or 4 miles west of the oil field.

The second unit or member of the Wilcox recognized in this area is much more sandy than that at the base. The unconsolidated materials are distinctly sandy, often pure sands, or light-gray sandstones. Some sandy clays are present. This sandstone member of the Wilcox incloses the oil field on all sides. It is seen on the downthrow side of the fault at San Marcos River and at a few other localities, as in the north part of the field where cross-faulting or abrupt dips bring it to the surface. To the east and southeast of the field this sandstone again appears by reason of the southeast dip of the formations. In other words, the Lower Wilcox exposed in the field is an inlier surrounded by the later Wilcox sandstone and sands.

THE GEOLOGIC SECTION

The formations drilled through to reach the producing horizon in the Luling field are, in order from the surface, Eocene—the Wilcox (basal part only) and Midway; Upper Cretaceous—Navarro, Taylor, Austin, and Eagleford; Lower Cretaceous—Buda, Del Rio, and Georgetown, terminating in the Edwards. These formations, especially from the Austin to the Edwards, are well represented by cores taken from this field, the description of the formations which follows being based upon these cores.

In the study of these formations some six hundred cores have been examined in more or less detail. In connection with the exam-

ination of these cores many helpful suggestions have been received from Dr. J. A. Udden; the writer wishes to acknowledge, also, assistance received from T. L. Bailey and D. D. Christner. Mr. Bailey has examined the cores particularly with regard to the degree of dolomitization as determined by mineralogic examination of thin slides. Acknowledgment is made also of the co-operation received from all producers in the Luling field. From the operators and the field men the writer has received cores, logs, and helpful supplementary details relating to the various wells. The United North and South Oil Company in particular has cored extensively, six hundred or more cores having been supplied by this company.

Elevations of wells used in the preparation of the structural map accompanying this report were made by Mr. B. H. Habener, engineer of the United North and South Oil Company. Lists of elevations and maps which have been of service have been contributed by some of the other companies.

The investigations in the Luling field have been made by the Bureau of Economic Geology of the University of Texas in co-operation with the Oil and Gas Division of the State Railroad Commission. The Bureau investigations have been concerned with the geology of the field, while water troubles have been considered by the Oil and Gas Division. Water conditions, accordingly, are not discussed in detail in this paper.

EDWARDS FORMATION

The Edwards formation is characterized by a succession of strata which differ much among themselves, but with few exceptions are quite unlike the overlying Georgetown. Among the characteristic features of the formation as developed in the Luling field is a succession of porous dolomitic strata alternating with limestone, marl, and thin-shale horizons. In color the dolomite varies from nearly white to brown, being commonly a shade of brown. The dolomite is for the most part crystallized, each crystal being readily visible under the hand lens. These crystallized, porous rocks, usually brown in color, have a superficial resemblance to sandstones and are frequently logged as sands by the drillers. Fossils originally present in these rocks are for the most part removed by solution or

remain as casts only. Originally highly fossiliferous layers have in some instances become extremely porous and cavernous by the solution of the inclosed fossil shells, together with the more or less complete alteration of the rock to dolomite. Production is obtained in a large measure from these porous dolomitic horizons.

White, fossiliferous limestones occur occasionally. White, soft, and for the most part, non-fossiliferous rocks occur commonly, especially near the top of the formation, and are usually recorded in the driller's log as "'dobe." Flint layers and flint nodules are seen occasionally. A characteristic feature of the Edwards is the presence of strata made up very largely of foraminifera, chiefly of the milioline type. The forams are usually lighter in color than the matrix, each shell appearing as a minute speck in the light-gray rock. Occasionally the foram limestone is dark or nearly black in color, being more or less oil impregnated. The milioline limestone, so far as observed, is not found in the Georgetown formation, being confined in this section to the Edwards.

The cores indicate several, perhaps as many as five, limestone layers within the first 75 feet of the Edwards in the Luling field. These layers, which are not always pure limestone, but are in part dolomitized, may not be universally present or may vary in number and thickness in different wells. In addition to these limestones there are calcareous marls, as well as more or less calcareous shales. It does not appear probable, however, that limestones, marls, and shales combined make up as much as a total of one-half of the first 75 feet of the formation in this field. On the contrary, from the cores taken the combined thickness of the dolomitized layers apparently amounts to more than one-half of the formation for the first 75 feet. Below that depth the cores have not yet been taken in sufficient numbers to form an equally close estimate of the dolomitization of the formation.

The following data relative to cores will aid in indicating the character of the formation. Of 100 representative cores taken at a depth of from 1 to 100 feet in the Edwards formation in the Luling field, 51 are chiefly dolomite, that is, showing an excess of dolomite over limestone; 3 are approximately half-dolomite and half-limestone; 46 are chiefly limestone, or marly limestone. With

regard to the distribution of the dolomite it was found that of 25 cores taken within the uppermost 10 feet of the Edwards formation 17 show limestone in excess of dolomite, while 8 show an excess of dolomite over limestone. Of 21 cores taken between 10 and 20 feet in the Edwards formation, 9 show chiefly limestone; 3 are half-limestone, half-dolomite, and 9 are chiefly dolomite. Of 14 cores taken between 20 and 30 feet in the formation 7 are limestone and 7 dolomite. Below 30 feet in the formation down to 100 feet, dolomite cores predominate over limestone in the proportion of about 3 to 1. While these data may as yet be imperfect, they suggest increased dolomitization with depth for the first 100 feet.[1]

Of fossils found in the cores from the Edwards formation the most common are shells of the genus *Requienia*. The shells are usually altered to crystallized calcite and for the most part are amber-colored in section. Among the smaller fossils, foraminifera of the milioline group are abundant, particularly in certain of the limestone layers.

Not only are the rocks of the Edwards formation porous but they are in places cavernous. One such cavern was drilled into by the United North and South Oil Company, in their No. 2 well on the Chester Byrd lease. The Edwards was entered in this well at about 2,097 feet, and casing was set and cemented at 2,114 feet. The cavity was reached at a depth of 2,130 feet, at which level the drill dropped 2 feet. In an effort to fill this cavity there was put into the well 1 ton of bran; 100 sacks of cement mixture; 400 cement sacks; 2 or 3 tons of cotton-seed hulls; 8 wagon loads of Spanish moss; 25 bales of hay; 5 tons of shale; and an undetermined amount of drilling mud. Being unable to fill the cavity, drilling was continued to 2,214 feet, where casing was set and the well drilled deeper by star rig. Oil shows were recognized both above and below the cavity although the cavity itself contained sulphur water.

GEORGETOWN FORMATION

The Georgetown formation next above the Edwards is prevailingly a gray limestone, which drills medium hard and in cores

[1] The estimate of the amount of dolomitization is based on an examination by T. L. Bailey of thin sections of the rock under a petrographic microscope.

generally breaks irregularly or shelly. Alternating with the hard-rock ledges are softer layers, often recorded in logs as shales, probably chiefly calcareous shales or marls. At the top of the formation is a stratum of light-colored, highly fossiliferous limestone. Fossils found at this horizon include *Kingena wacoensis*, often abundant, and *Turrilites* sp. probably *brazoensis*. A polished surface of the rock shows that it is a very dense, close-grained limestone in which are imbedded well-preserved shells and shell fragments. Cores showing this phase of the formation have been obtained from the Pope well of the Luling Oil and Refining Company, where it lies at the top of the Georgetown, the *Exogyra arietina* marl of the Del Rio being only a few feet above. Some thinner layers of similar rock occur lower down in the formation. *Kingena* is likewise not confined to the top of the formation. From the Lee Byrd well of the United North and South Oil Company a core has been obtained which if correctly labeled as to depth indicates the presence of this fossil near the base of the Georgetown.

Most of the cores from the Georgetown below the upper hard limestone ledge are of gray, shelly limestone. In some ledges this limestone is somewhat glauconitic. In the Luling field glauconite is observed to be very generally present in cores coming from the upper half of the formation, but is rarely if ever observed in cores from the lower half. In the Austin section of the formation, however, glauconite is present in the basal layers of the formation. A feature of the rock, not, however, confined to this formation, is discoloration or blotches. The staining is confined probably to breaks or cleavage lines in the rocks through which water has gained entrance. Occasionally, also, one finds in this formation what appear to be trails or burrows of some animal. These markings also are stained dark, as in the case of breaks in the rocks, and doubtless for the same reason. Among the negative characteristics of the Georgetown are the general or complete absence of dolomitized horizons, no cores from it in the Luling district showing dolomite.

The average thickness of the Georgetown in this field is probably between 50 and 60 feet. In the Polk well of the Luling Oil and Gas Company, where the top and base of the formation are determined

within an interval of no more than a few feet, the thickness is about 58 feet.

The fossils of the Georgetown, commonly seen in cores, include *Kingena wacoensis*, abundant at the top of the formation, sparingly present at lower levels; *Turrilites* cf. *brazoensis*, seen only from near the top of the formation; *Gryphea washitaensis*, present throughout the formation; the *Alectryonia carinata*, abundant from near or above the middle part to the base of the formation.

DEL RIO FORMATION

The Del Rio formation as developed in this field consists in part of blue clays and in part of more or less indurated calcareous marls or shales. In general, the clays predominate in the upper part of the formation while calcareous clays and shales are prominent in the lower part. The intergrading of the Del Rio at its base into the Georgetown is more pronounced in this field than at the belt of surface outcropping of the formations.

The clays of the formation are to some extent characteristic. In color they are light blue. When broken the surface is seldom smooth, as in laminated formations, but as a rule breaks in a characteristic manner seldom seen in other cores, although approached perhaps by some cores from the Taylor formation. Cores from the lower one-half of the Del Rio are notably calcareous, this part being gray, approaching in texture and composition the underlying Georgetown. Without the fossils the lower part of the Del Rio in this field can scarcely be distinguished from certain of the shaly layers in the Georgetown. Fortunately the characteristic fossils of the formation are often present in the cores. An abundant and characteristic fossil of this formation is the rams-horn shell, *Exogyra arietina*. This fossil is rarely, if ever, seen in cores from the upper part, but is not uncommon in cores from the lower half of the formation.

The contact between the Del Rio and Buda formations is only occasionally well indicated in logs. However, by means of cores supplementing the logs the contact has been determined within narrow limits in several wells. In Cartwright 4, of the United North and South Oil Company, the Del Rio appears to be 55 feet thick, the contact with the Buda above and the Georgetown below

being approximately determined. In Pope 1, of the Luling Oil and Gas Company, the Del Rio is at least 55 feet thick. It may be somewhat thicker in this well, but is not likely to exceed 65 feet. The Del Rio is probably the most variable in thickness of the formations between the Austin and the Edwards. In this field it possibly varies from 50 to 70 feet in thickness.

BUDA FORMATION

The Buda, as seen in numerous cores, consists largely of very compact limestones varying in color from light gray to white and occasionally yellow. As a rule the rock is hard, although some chalky cores have been obtained. Occasionally the Buda is oil stained. Some glauconite is present, and as a rule this is bright green in color. The color of the glauconite, however, is doubtless dependent upon the amount of exposure to oxidizing agents. Near breaks in the formation, where water has entered, the glauconite may not retain its bright-green color. Cores containing glauconite have been seen from as high as 15 feet from the top of the formation and from within a few feet of the base. Hence the formation as found in this field may show glauconite at almost any level.

The contact of the Eagleford and Buda is recorded in numerous logs and is known also within narrow limits from the cores, but the base of the Buda is imperfectly recorded in the logs. In Cartwright 4, of the United North and South Oil Company, the Buda appears to have a thickness of 63 feet. This record, if correct, probably shows nearly the maximum thickness of the formation. In the well of the Joliet Oil Company, probably 63 feet is to be assigned to the Buda. The formation appears to vary in thickness in this field from 55 to 65 feet.

EAGLEFORD FORMATION

The Eagleford formation in the Luling field has commonly a thickness of from 27 to 32 feet. In some instances it is possibly much thinner. Cores from this formation indicate black shales alternating with calcareous shales and limestone ledges. The formation is frequently fossiliferous, in places containing an abundance of foraminifera. In several of the cores from near the top of the Eagleford, shells of foraminifera of several species occur in such

abundance as to make up distinct thin, light-colored layers alternating with the dark shale. *Inocerami* are common fossils in this formation. Fish scales and plant fragments are often abundant.

More or less gas is commonly present in the Eagleford, some of the wells having been gassers at this horizon. Shows of oil are likewise common in the Eagleford.

AUSTIN FORMATION

The thickness of the Austin formation is difficult to determine as the top of the formation is seldom accurately recognized. The relatively hard rock of this formation recognized as Austin in drilling has a thickness, according to drillers' logs, of 200–350 feet. Probably the actual thickness does not vary as much as these records indicate. It appears, however, that there is considerable variation in the thickness of the Austin.

Some layers in the Austin, as seen in cores from Caldwell County, present rather close resemblance to the Georgetown. The rock is gray in color and is stained in a manner very similar to the Georgetown staining. Although resembling the Georgetown, this phase of the Austin may frequently be distinguished from that formation by the abundance of *Inocerami*, which are rare in the Georgetown.

About 60 feet above the base of the Austin is a shelly impure limestone containing an abundance of *Exogyra laeviuscula*. This fossil has a superficial resemblance to *Exogyra arietina* of the Del Rio, although it is readily separated from that species.

TAYLOR AND NAVARRO FORMATIONS

The Taylor marl contains hard layers which in advance of coring have not infrequently been mistaken for the Austin. When cored, the Taylor is found as a rule to contain a higher percentage of clay than does the Austin formation. The thickness of the Cretaceous above the Austin is probably about 1,000 or 1,200 feet, this interval including the Taylor and Navarro formations.

MIDWAY AND WILCOX FORMATIONS

Insufficient samples have been received on which to place the Wilcox-Midway contact. As already stated, the Wilcox is believed

not to exceed 50 or 100 feet in thickness. This inference is based on the occurrence within 50 feet of the surface of a dark, micaceous, highly fossiliferous shale, seen in a shallow well on the Meriweather farm, similar in character to shale elsewhere known to lie near the Midway-Wilcox contact. The contact of the Midway and Navarro is likewise undetermined. Probably 300 or 350 feet should be assigned to the Midway.

STRUCTURE

The controlling structural feature in the Luling field is a faulted anticline which trends about N. 30 E. From the bottom of the syncline at the west to the crest of the anticline is a distance of approximately $\frac{8}{10}$ mile, the Edwards formation rising a maximum of about 450 feet in this space. From the crest of the anticline the dip to the southeast is less abrupt, amounting on the average to probably between 150 and 200 feet in the first mile. That the structural conditions may be greatly complicated is indicated by Gideon No. 3 well of the United North and South Oil Company, in which the producing horizon is approximately 400 feet lower than in the offset well to the west.

The abrupt drop in the formations to the northwest is brought about in part by faulting, and production so far as known at this time is limited at the west side of the field by the fault, the downthrow of which is possibly between 50 and 100 feet. The strike of this fault is about N. 30 E., perhaps becoming slightly more easterly in the northern third of the field. The fault does not continue as a straight line through the field, but, aside from the slight change of direction referred to, has at least one small offset amounting to 250 or 300 feet, on the Merriweather and Cosey properties. Cross-faulting is apparently responsible for the offset in the main fault. The cross-fault has not been seen at the surface and is determined from well records only. Its direction appears to be at right angles to the main fault, its throw being 10 or 20 feet, and its downthrow to the south. The main fault is seen on the left bank of San Marcos River, on the A. J. Brown property. On the Proctor farm abrupt west dips are seen which doubtless represent the drag into the fault. On the Cosey farm, at the location of the Witherspoon and Grayburg wells, the very sandy soils indicate the downthrow side of the

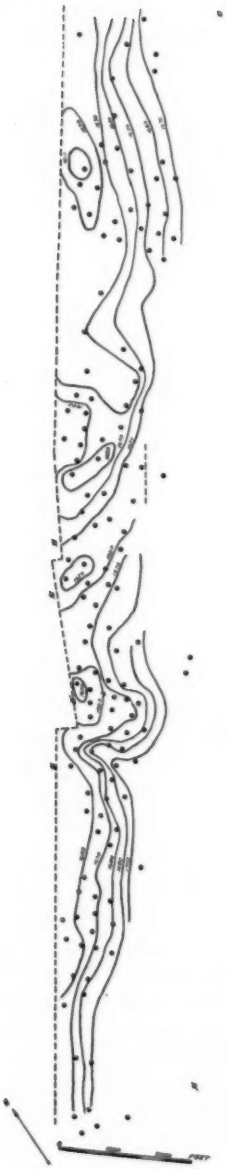


FIG. 1.—Structure map of the Luling oil field in Caldwell County. Contours show below sea-level depth on the top of the Edwards formation. Trace of fault on the Edwards formation indicated by broken line.

fault. On the Tabor farm, likewise, are abrupt dips indicating drag into the fault.

While the strike of the fault is approximately N. 30 E., the strike of the Eocene formations is N. 38 or 40 E. The fault, if continued northward without change of direction, would therefore ultimately cut the Midway at the surface. However, that it at least does not continue in a direct line is indicated by both the surface geology and by the well records. Also since the fault cuts diagonally across the strike of the formations it is to be expected that, the throw remaining the same, the structurally highest part of the field will be toward its north end. That this is true is indicated by the well records, the high point in the structure in Caldwell County being near the north end of the field.

For the purpose of structural studies the top of the Edwards is believed to be the most reliable. As they approach the producing level the drillers observe formation changes more closely than at higher levels, which affords on the average a better log; also many cores are taken at and near this level. Aside from oil shows, the change in drilling conditions upon entering the Edwards is

usually noticeable to the driller. To contour upon the "pay" is less reliable since production is obtained at varying depths in the Edwards. Some other contacts are quite well marked, as the base of the Austin, the Eagleford shale, and the clay phase of the Del Rio. At these levels, however, fewer cores have been taken than where approaching the pay. On the whole, therefore, the top of the Edwards is the most reliable for contouring. Details of the structural features in the field are shown on the map (Fig. 1). The broken line on the map indicates the trace of the fault at the producing horizon. The trace of the fault at the surface is found a variable distance to the east of the broken line. North of the middle part of the field as developed in Caldwell County the surface trace of the fault is probably no more than a few hundred feet to the east of the fault at the producing horizon, the dip of the fault plane being very steep, approaching the vertical. Toward the south the fault plane apparently dips less rapidly, giving an increased distance between the surface trace and the trace on the Edwards formation.

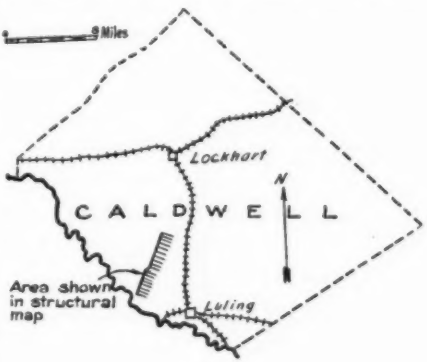


FIG. 2

CONCLUSION

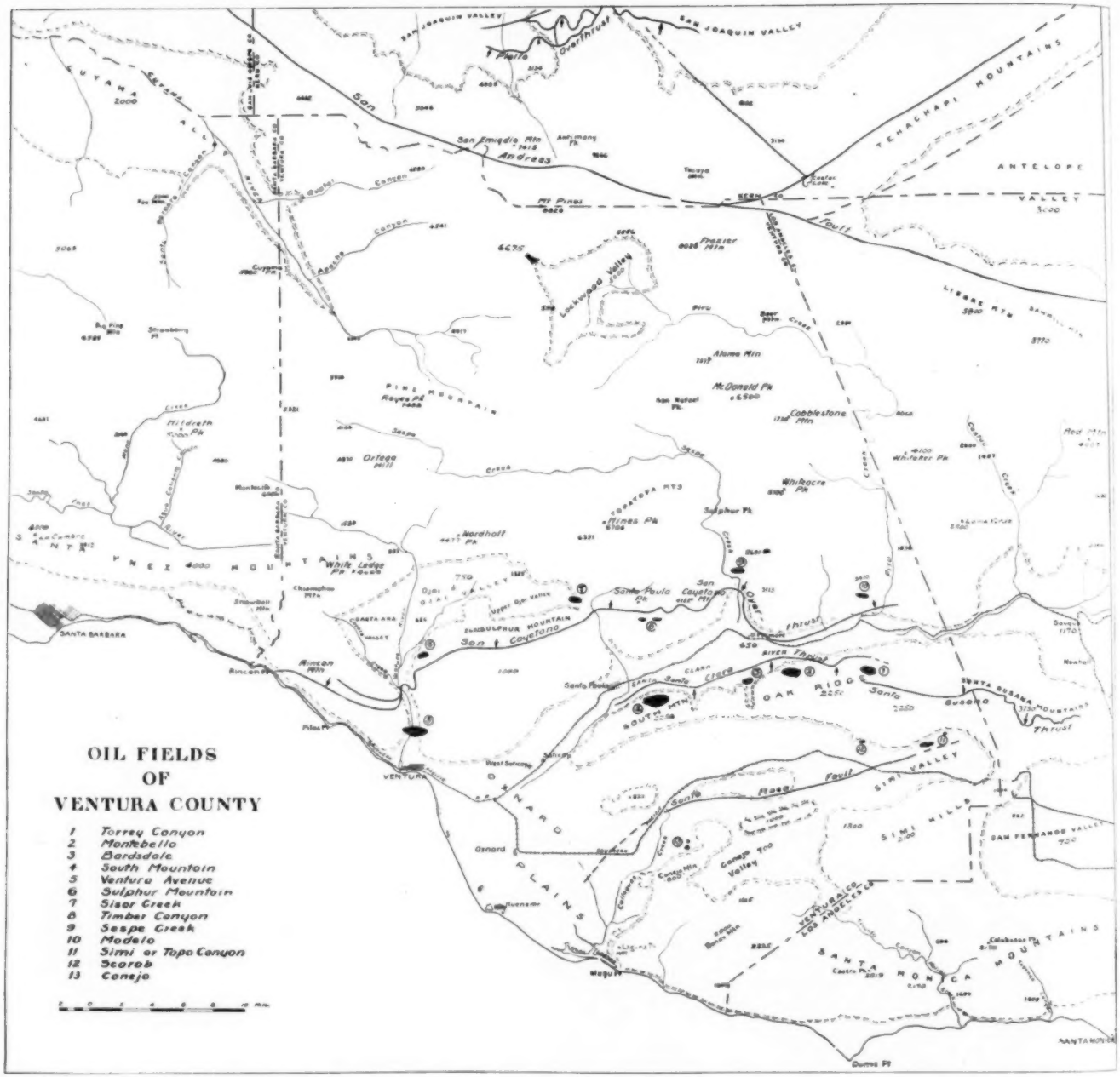
The Luling field presents many problems, some of which may be mentioned at this time. Of importance among these is the question of the alteration of the limestone to dolomite. Did this change in the rock occur at the time of deposition, that is, while the beds were being accumulated in marine waters? Or, has this alteration taken place subsequent to the deposition of the rocks? The fact that the rock is highly dolomitized in certain layers and scarcely at all in others suggests dolomitization subsequent to deposition, the rock being changed to dolomite in the strata through which the water was able to find passageway. If changed to dolomite subsequent to

deposition, did this change take place before or after the faulting? The numerous wells drilled into the Edwards in this part of the state, as well as the outcropping exposures, indicate that the Edwards formation is very generally more or less dolomitized. It does not seem necessary, therefore, to postulate faulting in order to account for the dolomitized zones in the formation. It seems more probable that the rock was altered to dolomite subsequent to deposition, but previous to faulting. If this is true the rock was in condition to form a storage reservoir for oil as soon as faulting brought about the present structural conditions.

A third problem which the writer will not attempt to discuss at this time is that of the origin of the oil, whether originally from the Edwards or from some higher or lower formation.[1]

It will be seen therefore that the Luling field presents first of all one feature new to the Texas Gulf coastal plain—production of oil in commercial quantity from the Edwards formation. It affords, likewise, very important unsolved problems in rock alteration and oil accumulation.

[1] A deep well drilled since this manuscript was written has shown that the Cretaceous in this field rests directly upon schists probably of Pre-Cambrian age. In this well, drilled by the United North and South Oil Company on the Tabor lease, the schists were entered at a depth of 4,796 feet from the surface. The whole thickness of the Lower Cretaceous at this locality as indicated by this well is about 2,850 feet.


OIL FIELDS
OF
VENTURA COUNTY
1 Torrey Canyon
2 Montebello
3 Bardsdale
4 South Mountain
5 Ventura Avenue
6 Sulphur Mountain
7 Sisar Creek
8 Timber Canyon
9 Sespe Creek
10 Modelo
11 Simi or Tapo Canyon
12 Scarab
13 Conejo
SAN JOAQUIN VALLEY
San Andreas
Fault
TEHACHAPI MOUNTAINS
ANTELOPE VALLEY
SANTA BARBARA
VENTURA
OAK RIDGE
SOUTH MTN.
SIMI VALLEY
SIMI HILLS
SANTA MONICA MOUNTAINS
SANTA SUSANA MOUNTAINS
Thrust
Santa Clara River
Santa Paula
San Cayetano
Mt. Pinos
Frazier Mtn.
Lockwood Valley
Alamo Mtn.
Mt. Donald Pk.
Cobblestone Mtn.
Whitaker Pk.
Sulphur Pk.
Hildreth Pk.
Ortega Hill
Wardhoff Pk.
White Ledge Pk.
Rincon Pt.
Pitas Pt.
Oxnard
Mugu Pt.
Point Dume
SANTA MONICA

THE OIL FIELDS OF VENTURA COUNTY, CALIFORNIA

N. L. TALIAFERRO, F. S. HUDSON, AND W. N. CRADDOCK

I. NOTES ON THE GEOLOGY OF VENTURA COUNTY, CALIFORNIA

N. L. TALIAFERRO

INTRODUCTION

The present paper is intended as an introduction to the papers on the two important oil fields of the county by F. S. Hudson and W. N. Craddock, in which the geography, stratigraphy, structure, and a brief description of the various fields in Ventura County will be outlined. No references to the geologic literature on the subject are given, but special acknowledgment must be made of the publications by Eldridge and Arnold, Louderback, and Kew, since these form the basis for much of our present knowledge of the Tertiary history in this region. At the present time data are being collected by Mr. Hudson and the writer for a detailed account of certain of the oil fields of the county, and a more complete paper will be presented at a later date.

GEOGRAPHY

Ventura County extends northward from the Pacific Ocean to the crest of the high mountainous region just south of the southern end of the San Joaquin Valley (Plate VII). The southern part of the county is made up of relatively low ranges separated by shallow valleys and by one coastal plain formed by the junction of several valleys, the largest of which is the Santa Clara.

The chief topographic features, from south to north, are the Santa Monica and Conejo mountains, the Simi and Las Posas valleys, the Oxnard Plain, the Santa Susana–South Mountain ridge, the Santa Clara Valley, and the very complex, high, rugged mountainous area which occupies the entire northern half of

the county. All of these features have a general east-west trend, except the valley of the Santa Clara, which, after following an east-west course through the eastern and central part of the county, turns to the southwest across the general trend of the topography and structure and enters the ocean between Ventura and Oxnard.

The Santa Monica Mountains extend from the city of Los Angeles, westward along the coast into the extreme southern part of Ventura County, where they are generally known as the Conejo Mountains. This range has a maximum elevation of 3,000 feet, the average elevation of the crest being considerably lower. In Los Angeles County it is separated from the Santa Susana Mountains by San Fernando Valley; in Ventura County the separation is less clearly marked and the Santa Monica and Santa Susana mountains are separated by relatively narrow, shallow valleys. The Simi Hills, having a northeasterly trend, form a connecting link between the two mountain groups.

North of the Santa Monica Mountains and Simi Hills are the Simi and Las Posas valleys, which are separated by a very low pass between Simi and Moorpark. Las Posas Valley merges into the Oxnard Plain—a broad, featureless area lying west of the Conejo and Santa Monica mountains and extending to the ocean.

The most important valley is the Santa Clara, which has an east-west trend throughout most of its course but which turns to the southwest in the southcentral part of the county and merges with the Oxnard Plain. South of the Santa Clara Valley, and north of the San Fernando, Simi, and Las Posas valleys is a long ridge, the western extension of the San Gabriel Mountains. Although this is in reality a single topographic unit, different names are applied to various parts; the eastern end, between Newhall Pass and Torrey Canyon, is called the Santa Susana Mountains; the central part, between Torrey Canyon, on the east and Sulphur Canyon on the west, is known as Oak Ridge, while the extreme western end is called South Mountain. This range gradually becomes lower toward the west and finally dies out just east of the town of Saticoy, where Santa Clara Valley merges with the Oxnard Plain. The crest of the Santa Susana Mountains, which end near the eastern edge of Ventura County, has an elevation of 3,000 to 3,750 feet. Oak

Ridge is simpler both topographically and geologically and has an even crest line not exceeding 2,200 feet in elevation.

North of the Santa Clara Valley the mountains rise abruptly and the crests of their ridges attain, within a short distance, elevations of 6,000 to 7,000 feet; even the valleys are usually over 4,500 feet above sea-level. The highest point in the county is Frazier Mountain, in the extreme northeastern corner, with an elevation of over 8,000 feet. Owing to the rugged nature of the country, the high relief, and the scarcity of roads and trails, the northern part of Ventura County is one of the most inaccessible regions in California. Although this mountainous area contains many ridges and peaks which have been named, no general name has been applied to the region as a whole. This is largely due to the fact that it lies at the junction of three of the most important mountain systems of California—the coast ranges, the Sierra Nevada (or rather their southern continuation, the Tehachapi Mountains), and the east-west-trending desert ranges. All of these major systems meet in northern Ventura County, and all influence the topography and geology to a certain extent.

Topographically and geographically this mountain group is more closely related to the coast ranges than to the other mountain systems. One striking difference is that the general lines of structure have an east-west trend whereas in the coast ranges the typical direction of folding is northwest-southeast. Even the San Andreas Rift, which has a northwest trend throughout most of its course, bends to the east along the northern boundary of Ventura County.

GEOLOGY

Nearly all of the major divisions of the sedimentary rocks found in the coast ranges occur in Ventura County and, in addition to these, there are, in the northeastern part, granites and schists very similar to those occurring in the Sierra Nevada. The Tertiary is exceptionally well developed, and all of the principal formations of this system are represented, covering in areal extent fully four-fifths of the county. Although a thick section of the Cretaceous is exposed in the Simi Hills, in the southeastern part of the county, its distribution is limited to a very small area. The Franciscan forma-

tion (Jurassic or possibly Triassic), which is so widespread in the coast ranges to the north, is not present, although it occurs in the San Rafael Mountains, a typical coast range type, not far west of the western border of the county. This formation is probably present beneath some of the younger rocks.

The Tertiary is largely made up of terrigenous material, but during certain periods, notably the Miocene, there were great accumulations of biogenic shales. The Miocene was also a time of great volcanic activity resulting in lava flows, tuffs, agglomerates, and intrusions of igneous rock.

The coast ranges were an unstable province throughout the Tertiary, and the relation between land and sea was constantly changing. Not only were there broad epeirogenic movements affecting the region as a whole but also numerous, more or less local, orogenic movements which caused the elevation or depression of relatively small blocks of the earth's crust. Owing to the numerous local movements, unconformities, often very pronounced, occur at many places throughout the section and quite commonly within the same series of beds. This has given rise to a rather large number of formational names which, however valuable they may be in certain localities, are often of doubtful value in a consideration of the broader features of sedimentation. It is impossible, of course, to correlate definitely all of the various formations over wide areas, but the naming of numerous new formations which are the result of more or less local unconformities and which may contain slightly different faunas is to be discouraged as it often leads to unnecessary confusion.

Two unconformities occur within the Eocene, dividing it into three formations, each with a distinctive fauna and more or less distinctive lithologic characteristics. The evidence afforded by the attitudes of the beds indicates that these unconformities do not represent important orogenic disturbances and the time breaks are probably comparatively short.

The Miocene appears to have been a very unstable time as there are numerous local unconformities and changes in type which might indicate corresponding changes in the relation between land and sea. The orogenic movements were accompanied by rather wide-

spread volcanic activity. Certain well-defined lithologic types occur throughout most of the Miocene, and its character is such that it can be recognized readily nearly everywhere.

The close of the Miocene was marked by major orogenic movements which have resulted in probably the most pronounced unconformity in the Tertiary section, the Pliocene resting on all the older rocks with marked unconformity. The present system of ridges and valleys was outlined at this time. Another great period of movement took place in the Pleistocene, and the resultant folds coincided in general with, and accentuated, those formed in the early Pliocene. The great thrusting movements in central Ventura County and in southern Kern County took place during the Pleistocene.

The following is a brief description of the various formations occurring in Ventura County and their relations to the occurrence of oil.

PRE-CRETACEOUS

The only pre-Cretaceous rocks known in the county occur in the extreme northern and northeastern parts. Here, near the junction of the three mountain systems referred to above, there are schists and other metamorphic crystalline rocks intruded by granite. The age of the metamorphic rocks is not definitely known but they closely resemble the Calaveras (Upper Paleozoic) and are tentatively correlated with this group. The granites and other holocrystalline intrusives are probably of Jurassic age. These rocks form the crystalline basement complex upon which the later rocks rest.

UPPER CRETACEOUS

Chico formation.—The only Cretaceous beds thus far recognized in the county occur along the crest of the Simi Hills and extend across Santa Susana Pass into the southern part of the Santa Susana Mountains, where there is a thickness of over 5,000 feet of buff to brown sandstone, occasionally conglomeratic, with minor amounts of dark-gray or olive-green shale. The sandstones are fairly well indurated and stand out boldly; they are excellent for building purposes. These beds dip to the north-northwest in the Simi Hills,

the dip gradually changing to west-southwest north of Santa Susana Pass, thus forming the eastern end of the Simi Valley syncline. There are no organic shales in this series and it has no bearing on the occurrence of oil in the region.

TERTIARY

EOCENE

The Eocene is exceptionally well developed and widespread in Ventura County, all three of the recognized divisions being present. Along the northern flank of the Simi Hills and on the northeastern edge of Simi Valley the three Eocene formations, separated by unconformities and containing distinct faunas, are present. North of the Santa Clara Valley, in the Topatopa Mountains and extending westward into the Santa Ynez Mountains in Santa Barbara County, is a long belt of Eocene beds of Meganos and Tejon age. The Martinez has not been recognized in this area.

Martinez formation.—This formation overlies the Chico beds unconformably in the Simi region, where it consists of a basal conglomerate overlain by dark sandstones and shales. The conglomerate and sandstones are confined to the lower part, the upper being predominantly bluish-gray and brown shale. Although no seepages are known to occur in the Martinez, the shales are a possible source of oil.

The Martinez outcrops in a belt of varying width parallel to and west and northwest of the Chico formation. It extends from the foothills of the Santa Susana Mountains across the east end of Simi Valley and then swings to the southwest and west along the northern flank of the Simi Hills. The maximum thickness, 2,500 feet, occurs north of Simi Valley and west of Santa Susana Pass; it thins westward to less than 500 feet.

Meganos formation.—In the Simi region the Meganos beds consist of dark-gray and bluish sandy shales with minor amounts of shaly sandstone and occasional lenses of conglomerate. The shales are similar to those in the upper part of the Martinez and also to the thin shale intercalations in the Tejon. They are probably the source of the oil found in the Tapo Canyon field and possibly the source of the oil in the Oak Ridge–South Mountain fields.

The unconformity between the Meganos and the Martinez is brought out by areal mapping rather than by any marked difference in attitude of the beds. The Meganos parallels the underlying Martinez and outcrops north of Simi Valley, just west of Tapo Canyon. It is concealed by alluvium in Simi Valley but reappears on the south along the north flank of the Simi Hills. The maximum development, more than 2,500 feet, is attained on the north side of Simi Valley; to the west it thins rapidly and finally disappears, owing to unconformable overlap by the Tejon. The Meganos has not been separated from the Tejon north of the Santa Clara Valley, but it is probably present in places.

Tejon formation.—This formation is the most widespread and thickest of the divisions of the Eocene, not only in Ventura County but in the state as a whole. It consists predominantly of massive, often cross-bedded, light-colored sandstones, lenses of conglomerate, and minor intercalations of shale.

In the Simi region the Tejon is represented by only a few hundred feet of sandstone which occurs in and just east of Tapo Canyon north of Simi Valley. Unlike the underlying Eocene formations, the Tejon thickens toward the west and attains its maximum thickness, between 2,000 and 2,500 feet, in the western end of the Simi Hills.

North of Santa Clara Valley the Eocene is represented by 3,000 to 6,000 feet of hard sandstones, quartzites (really very hard, silica-cemented sandstones), and shales. The Martinez is probably absent, but some of the beds are thought to represent the Meganos. The bulk of these sediments, however, are undoubtedly of Tejon age. These beds have been called the Topatopa formation, but since they contain an Eocene fauna and are lithologically similar to the Tejon throughout California it seems better to drop the unnecessary formational name, Topatopa, and refer to them as Tejon, with the understanding that they probably contain, here and there, some beds of Meganos age.

West of Sespe Canyon, in the heart of an anticline along Coldwater Creek, and again to the north along the southern flank of the Topatopa Mountains, there are about 400–500 feet of hard white sandstones with intercalations of light-pink, pale-green, and grayish

shales. The sandstones carry a dwarfed estuarine fauna of Eocene age. These beds have heretofore been included with the Sespe, but since they are fossiliferous and also differ lithologically from the typical Sespe they should be included in the Tejon as the Coldwater member.

The Eocene north of Santa Clara River occurs in the major structural and topographic uplift which runs from the Topatopa Mountains westward through Ventura and Santa Barbara counties, and is also exposed on San Cayetano Mountain between Sespe and Santa Paula creeks where it has been thrust over the Miocene and Pliocene.

Small amounts of oil are obtained from the Eocene in the Tapo Canyon field on the north side of Simi Valley and along Tar Creek just south of the Topatopa Mountains. A little heavy oil was encountered in the upper part of the Eocene in the Red Mountain dome 6 miles northwest of Ventura. It is generally assumed that the oil obtained in the Sespe formation in Ventura County has its origin in the Eocene shales. This assumption has considerable support but there are other possible sources for the oil.

OLIGOCENE(?)

Sespe formation.—Resting on the Tejon is a very thick series of varicolored fluviatile and lacustrine beds termed the Sespe formation, so called from its type section in Sespe Creek north of the town of Fillmore. The attitude of the underlying Tejon and the overlying Sespe beds is everywhere practically the same and the unconformity between them, if one really exists, can be brought out only by detailed mapping in critical areas. There is probably a slight unconformity between these two formations as the conditions under which they were deposited differed widely, the Tejon being marine and the Sespe continental. Locally there are estuarine beds which are apparently transitional between the two (Coldwater member of the Eocene), but these beds are limited in their distribution.

Owing to the absence of fossils in the Sespe there is some doubt as to its exact age. However, since it lies above the Upper Eocene and below the Lower Miocene it is generally regarded as Oligocene.

The Sespe consists of 4,000 to over 6,000 feet of red, yellow, and white sandstones; red, maroon, gray, and green sandy shales; and numerous lenses of conglomerate. The rapid lateral variation, the general character of the beds, and the absence of fossils indicates that this series was deposited on land. Relatively thin lacustrine deposits occasionally occur, indicating that there were small lakes in the basin in which the Sespe was deposited. These lake deposits are characterized by very pure sticky, finely banded red and white clays with a few thin layers of very salty white clay. The Sespe evidently represents a continental deposit laid down under rather arid conditions.

The Sespe as a whole, wherever it occurs, is characterized by bright red sandstones and red and green sandy clays. With the exception of the area north of the Santa Clara Valley the Sespe is soft and easily eroded and has a strong tendency to form topography of the bad-land type.

The Sespe is widely distributed in Ventura County, being exposed both north and south of Simi Valley, in the crests of the domes along the north side of Oak Ridge and South Mountain, in the Red Mountain dome northwest of Ventura, on both sides of Ojai Valley, and along the lower part of Sespe Creek. It also occurs in the Cuyama Valley in the extreme northwestern corner of the county and in the Santa Monica Mountains in Los Angeles County. It outcrops in a narrow belt along the southern side of the Santa Ynez Mountains from Ojai Valley in Ventura County to, and slightly beyond, Gaviota Pass in Santa Barbara County, a distance of 60 miles.

Oil occurs at several horizons in the Sespe in the domes along the Oak Ridge–South Mountain uplift, in Sespe Canyon, and in a small area north of Simi Valley. It is necessary to postulate some other source for the oil than the sandy Sespe clays as they are wholly lacking in organic material of any kind.

MIOCENE

The Miocene is the thickest, most complex, and most widely distributed of any of the Tertiary series in the coast ranges of California. There is less uniformity of nomenclature for the various

formations of the Miocene than in any of the other Tertiary series, due primarily to the fact that during the Miocene orogenic disturbances were much more frequent than at any preceding time in the Tertiary, these movements naturally resulting in many more or less local unconformities. In some parts of the coast ranges conditions appeared to have been more stable and the entire Miocene section appears to be practically conformable whereas in other areas the same beds are separated by marked unconformities.

A very distinctive type of sedimentation took place during the Miocene, resulting in the great thickness of biogenic shales which were deposited throughout the coast ranges. The general sequence is a basal sandstone, the Vaqueros, followed by shale, much of which is biogenic. This sequence is interrupted in many places and in some localities there are thick sandstones intercalated in the organic shale sequence, and these sandstones are often much thicker than that representing the beginning of Miocene deposition. In some places, especially near the old land masses, the Miocene is represented by sands, gravels, and sandy clays, the biogenic shales being absent or represented only by very thin beds.

As early as 1855 these diatomaceous shales were referred to under the name "Monterey," from their occurrence near the town of that name. Since that time the lower sandstone, as well as those higher in the section, have been included with the shales, the whole being referred to as the "Monterey series." That there are local unconformities in this series, that it varies from place to place, and that lithologically similar members may not have been deposited at exactly the same time in various localities is admitted. However, the name has become so familiar, the general sequence is so similar, and the type of sedimentation so characteristic that the writer considers the name "Monterey series" should be used to include all the sandstone–biogenic shale series, in spite of local unconformities and variation in sedimentation which may exist. In certain regions it is often advisable, even necessary, to divide the Miocene into formations. However, these divisions should not be made at the expense of the well-known Monterey series for the reasons enumerated above.

In Ventura County the Miocene is represented by an exceptionally thick series of sandstones, terrigenous shales, and white diatomaceous shales, often with hard cherty layers and lenses of impure foraminiferal limestone. The sections on the two sides of the Santa Clara Valley differ considerably in that on the north side there are two thick sandstone members within the biogenic shale which are lacking on the south side. This is probably due to the fact that the land mass from which the terrigenous sediments were derived lay to the north and that relatively slight movements caused a migration of the strand line.

In the Santa Clara Valley region the Sespe is overlain conformably by the Vaqueros. In this area the beginning of the Miocene was marked by a gradual encroachment of the sea unaccompanied by orogenic movements, and usually there is a gradational contact between the Sespe and Vaqueros. However, the rather sudden and striking change in conditions of deposition, from non-fossiliferous continental to fossiliferous marine sandstones closely followed by biogenic shales, warrants the separation of the two series.

It has been suggested that the Sespe is merely a non-marine phase of the Vaqueros and in some areas there is much to recommend this theory. However, the great thickness of the Sespe, its distinct lithologic character, and the fact that it was strongly folded in some regions prior to the deposition of any Miocene sediments is sufficient justification for the separation of the Sespe as a distinct formation in the Santa Clara Valley.

The Monterey series occurs between Little Sespe and Piru creeks, where it has been thrust over the Fernando, along the south side of Santa Paula Ridge, and on Sulphur Mountain, where it lies below the Tejon and Sespe owing to thrusting. South of Santa Clara Valley it occurs along the Santa Susana Mountains, Oak Ridge, and South Mountain, where it forms the south limb and the saddles between the domes on the Oak Ridge uplift. Equivalent sediments occur over a large part of northern Ventura County. In the extreme northwestern corner, in Cuyama Valley, marine Miocene beds grade eastward toward the mountains into continental deposits.

On the west and south flanks of the Simi Hills and in the Santa Monica Mountains there is a series of beds, lying on the upturned edges of the Sespe and Eocene, and having the same general sequence as the Monterey, namely, sandstones followed by biogenic shales. This series contains a Miocene fauna which differs slightly from, and is younger than, the Vaqueros. It has been called the Topanga, from its development in the canyon of that name in southwestern Los Angeles County. The writer knows of no locality in Ventura County where this formation rests on beds younger than the Sespe. In southern Ventura County, while probably not exactly equivalent in time with the Vaqueros and the overlying shale, it represents a phase of the Monterey series, a slightly later encroachment of the sea on what was probably a land mass at the beginning of Miocene time. Associated with this formation are basic flows and agglomerates and intrusions of basalt, andesite, dacite, and diabase.

The Monterey series is an important source of oil in practically all of the oil fields of California. In Ventura County about half of the present production comes from the Monterey or from Fernando sandstones (Pliocene) immediately overlying it.

Conejo volcanics.—Volcanic activity was widespread in California during the Miocene, and tuff, flows, and intrusions are fairly common in the Monterey series. One of the most important centers of Miocene vulcanism in the state lies in the western end of the Santa Monica Mountains. This region is often referred to as the Conejo Mountains, and the name "Conejo volcanics" is here applied to all the series of volcanic and intrusive rocks occurring in that region.

Associated with these volcanic rocks are Miocene sediments which were accumulating during the volcanic activity. In the lower part of the section the sediments are dark olive-green shales, yellow sandstones, and thin-bedded cherty shale, all of which are frequently tuffaceous. The shales are extremely micaceous and contain an abundance of carbonized wood fragments and occasionally fish scales but are not otherwise fossiliferous, and it is not definitely known what part of the series they represent. They are thought to be Lower Miocene. These sediments are very intimately associated with the volcanics and in places agglomerate grades both upward and laterally into sandstones. The cherty

layers become more numerous higher in the section, and to the east of the line of the section, given below, thick lenses of cherty and biogenic shale are apparently interdigitated with the volcanics.

The volcanics and the interbedded sediments dip north, at angles of 15°–32°, from Mugu Point on the coast to Santa Rosa Valley. The general succession from Mugu Point northward is as follows:

	Feet
Chiefly agglomerates and flows of basalt, with some andesite. Cut by small dikes of basalt, andesite, and dacite	4,500+
Cherty shales, sandstone, dark clay shales, tuff, agglomerate, and a few flows	2,500
Dark olive, clay shales, gray and yellow sandstones, and tuff, with sills of diabase. There are a few layers of andesite and basalt agglomerate	5,000
Same as foregoing except that the diabase sills are thicker and more numerous, the intrusives being about equal in thickness to the sediments	3,000
Base not exposed	
	15,000+

This rough section, measured across the strike, represents the exposed thickness of the Conejo volcanics and the associated Miocene sediments across one of the most important centers of Miocene volcanic activity in California. However, since there were probably several local centers of volcanic activity with local accumulations of volcanic material about them, which may have thinned very rapidly in all directions from the centers, it is possible that no one vertical section, with a thickness of 15,000 feet, was ever built up in any one place in the Conejo region.

The upper flows and agglomerates thin rapidly toward the north and east and the interbedded sediments thicken. There is a relatively thin layer of agglomerate at the base of the Topanga formation in the western end of the Simi Hills, and there is a thin layer of basalt in the Vaqueros on the south slope of Oak Ridge. Basalt was encountered at a depth of 2,860 feet in a well on Las Posas Ridge, about halfway between Conejo Mountain and South Mountain. In the South Mountain oil field there is a dacite sill between the Sespe and Vaqueros.

One feature which should be mentioned is the almost complete absence of tuff in the Miocene formations not immediately associated with the volcanics. A few very thin layers of tuffaceous material have been reported but they are relatively rare. This fact, together with the presence of marine sediments interbedded with the agglomerates and flows, clearly indicates that the volcanic outbursts were almost wholly, if not entirely, submarine.

PLIOCENE

Fernando group.—The Fernando group has been divided into two formations in southern California—the Pico and the Saugus. They are separated by an unconformity but this is not in every place visible, as the two formations are in places practically identical in lithology. As a whole, the Pliocene consists of conglomerates, sands, sandy shales, and clays which are always soft and easily eroded. These beds rest unconformably on all the underlying beds, frequently with very marked difference in attitude.

The oil horizons in the Ventura Avenue field occur in the lower part of the Fernando, and seepages are found in these beds in other parts of the county.

STRUCTURE

Like the coast ranges as a whole, the structure in Ventura County is very complex, owing to the various periods of severe orogenic movements which have affected the beds. Thrust faults, often of considerable magnitude, have been produced, chiefly along the edge of the mountains fronting the valleys.

Orogenic movements took place throughout the Tertiary but they were especially severe during the Miocene and at its close. Probably the most important movements took place just before the deposition of the Lower Pliocene, since beds of that age frequently rest on all the older strata with marked unconformity. It was during this period of folding that the present structural lines were formed. These movements arched the beds along the present folds and uplifted the mountains in the northern part of the county. During the Pleistocene, after the deposition of the Fernando, there was another period of diastrophism which strongly folded, faulted, and thrust all of the Tertiary beds. These movements tended in general to follow and accentuate the structural lines determined at

the end of the Miocene and usually the lines of previous folding were followed almost exactly; in some places, however, the crests of folds formed during the Pleistocene departed somewhat from those formed at an earlier time.

North of the Santa Clara Valley the structure is exceedingly complex, owing to numerous overturned folds and thrust faults of considerable magnitude. Both the northern and southern fronts of the high mountainous mass which occupies northern Ventura and southern Kern counties are characterized by great thrusting movements, the direction of which is always from the mountains toward the valleys. Along the southern front of this broad mountainous area there is a zone of thrusting, the surface trace of its sole extending from the coast near Rincon Point in the extreme western edge of the county to, and beyond, Piru Creek in the extreme eastern part, a distance of 40 miles. The Santa Susana thrust, south of the Santa Clara Valley, is a continuation of this line of thrusting. In the western part of the county, from Rincon Point along the front of Red, Sulphur, Santa Paula, and San Cayetano mountains as far east as Sespe Creek, the exposed surface angle of the fault dips about 30° north. In Sespe Creek and eastward the plane of the fault is exceedingly low, in fact almost horizontal. West of Sespe Creek the trace of the thrust is some distance back from the valley, but at Sespe Creek it swings out into the valley along the base of the hills. One line of thrusting crosses the valley near Piru and follows the southern side of the Santa Susana Mountains. Along the sole of the thrust the Fernando group has everywhere been overridden by older formations; back of this there are higher-angled branches which have thrust the Sespe over the Monterey, and the Tejon over both. Along the line of the accompanying section (Fig. 1) the Tejon has been thrust over the Fernando for a distance of more than 2 miles. This displacement is small compared with many thrust faults in other parts of the world, but it is sufficient to place it among the major overthrusts in California. The name "San Cayetano" is suggested for this fault since the mountain of that name apparently owes its elevation to movement along the thrust.

South of the Santa Clara Valley and west of the Santa Susana Mountains the structure is, for the most part, comparatively simple.

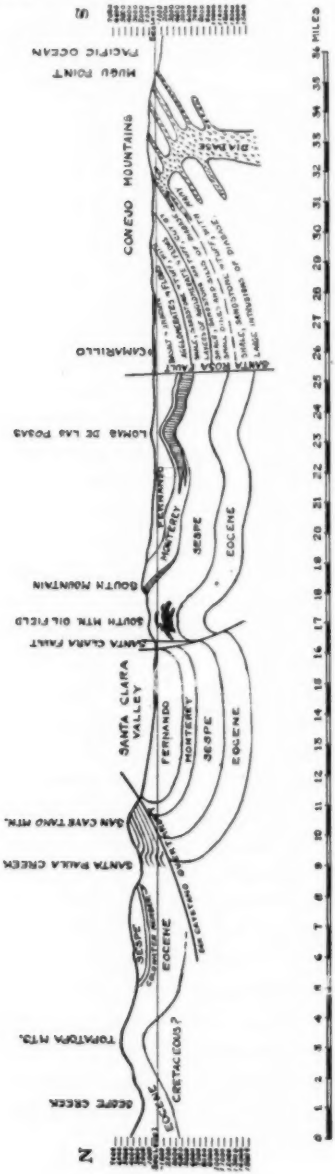


FIG. 1.—Structure section across the south central part of Ventura County

The Oak Ridge–South Mountain ridge represents an anticlinal fold whose crest lies along the northern flank not far south of the valley. This important line of folding crosses the Santa Clara Valley south of the town of Santa Paula and extends through the foothills north of the valley as far as the coast. This is not a continuous, uninterrupted anticline, but really a series of domes, separated by rather sharp sags, along a general line of uplift. The only really important oil fields thus far developed in Ventura County occur along these domes. East of the point where Santa Clara River cuts across this line of uplift the northern limb of tbe fold is steeper than the southern and, in some places, is even overturned. The evidence points to the presence of a high-angle thrust fault, with a decided northward component of movement, along the northern edge of Oak Ridge and South Mountain. This fault is concealed by the alluvium in Santa Clara Valley except at the mouth of Wiley Canyon, where the Monterey is thrust over the Fernando. The plane of the thrust here dips 45°.

The Santa Clara Valley is thus bounded by overthrusts in the stretch between Santa Paula and Piru, a distance of 16 miles. It is really a greatly compressed syncline whose edges have been overturned toward the center of the valley. Although there is no evidence as to the depth beneath the surface to which the Tertiary beds extend under the valley, Figure 1 is believed to be essentially correct in its details. Some evidence is afforded by a well near the center of the valley, not far east of the line of the section, which has already attained a depth of 4,175 feet (about 3,750 feet below sea-level) without reaching the base of the Fernando.

There is another line of uplift 6–7 miles south of, and parallel to, the Oak Ridge–South Mountain fold. This extends along the northern side of Simi Valley westward as far as Las Posas Ridge, 6 miles due south of South Mountain. This line of folding is not as well marked topographically or structurally as the uplift to the north. The only oil field along this line at the present time is on the extreme eastern end where a small production is obtained from the Eocene. Along this uplift the crest of the fold, as indicated by the Fernando beds, does not always agree with the crest of the fold in the underlying Monterey but lies from $\frac{1}{4}$ to $\frac{1}{2}$ mile to the north and parallel to the latter.

South of the Simi–Las Posas uplift is the Santa Rosa fault which extends from Simi Valley on the east to the town of Camarillo on the west with a trend of N. 75 E. It disappears beneath the alluvium of Oxnard Plain near Camarillo, but it is thought that it turns rather sharply to the south-southwest along the front of the Conejo Mountains. It is a normal fault, down-thrown on the south, and is probably due to the great accumulation of volcanic material in the mountains to the south. It was probably formed progressively with the accumulation of the volcanics.

OIL FIELDS

The unusually large seepages in Ventura County attracted the attention of oil operators at a very early date. As early as 1850 oil from seepages was refined by the Mexicans for illuminating purposes in the missions. The first wells were drilled about 1875, but it was not until late in the eighties that any appreciable production

was obtained. All of the early efforts were confined to the seepage-covered areas and the production obtained was very small.

Many large seepages, some of which cover many acres, are located along the faulted zone south of Ojai Valley and north of Santa Clara Valley. These seepages usually occur along faults, but they also may be found where oil sands are exposed. At many places in the area east of Sespe Creek oil seeps from the Monterey shales and the sandstones interbedded with them. Seepages are very rare in the more important producing fields.

There are a very large number of entirely separate oil fields in Ventura County but most of them are very small; at the present time three fields—Ventura Avenue, South Mountain, and Montebello—yield fully 95 per cent of the total daily production of 10,000 barrels.

For convenience the fields can be divided into three geographical groups which correspond fairly well with the geologic structure. All of the fields north of the San Cayetano thrust may be grouped together although they do not all obtain their oil from the same horizon. Another natural grouping is the line of fields extending along Oak Ridge and South Mountain and across Santa Clara Valley to the ocean. In the third group are the three very small fields in the southeastern part of the county.

In the intricately folded and faulted area north of the thrust there are many small groups of wells which obtain their oil either along faults or very sharp folds. Some of the oil is obtained in the Sespe formation, some in the Monterey series, and a very small amount in the Eocene strata. Nearly all of this oil is heavy. The most important field north of the thrust is the Modelo, located in Modelo Canyon, a branch of Piru Creek, in the eastern part of the county. Here oil is obtained in a very sharp anticline. The dips on the south flank average 55° and those on the north 50°. The oil is obtained from relatively thin sands in the Monterey (Modelo formation). So sharp is the fold that the productive area along the crest is barely two "locations" wide. The present daily production is less than seventy-five barrels of 27° to 29° Baumé oil. There are many areas north of the thrust in which small production can be obtained. However, the inaccessible nature of the country and the

small amount of production that can be expected will discourage active prospecting in this region for many years.

The only fields of present importance in the county occur along the Oak Ridge–South Mountain fold and its westward continuation across Santa Clara River, the San Miguelito anticline. The fields along this line, from east to west, are as follows: Torrey Canyon, Montebello, Bardsdale, South Mountain, and Ventura Avenue. All of these are on well-marked domes separated from each other by sharp structural sags. All of the fields south of Santa Clara Valley, along Oak Ridge and South Mountain, obtain their oil in the Sespe. The oil occurs in numerous, relatively thin, rapidly lensing sands interbedded in red and green sandy shales. In the Montebello field there is an upper, shallow group of sands, 150–700 feet deep, separated from a deeper group lying below 1,300 feet by a 400-foot sandstone carrying salt water. The shallow oil horizon at Montebello has been eroded away from the crest of the South Mountain dome, which is the highest uplift along this line of fields. The gravity of the oil in these fields usually ranges from 28° to 34° Baumé—although there is a very deep horizon at South Mountain in which heavy oil has been encountered.

It has usually been assumed that the oil in the Torrey Canyon, Montebello, Bardsdale, and South Mountain fields originated in the organic Eocene shales, which are supposed to be beneath the Oak Ridge uplift, and migrated upward into the overlying Sespe. This hypothesis finds considerable support from the fact that the Eocene shales are known to be an adequate source of the oil in other parts of Ventura County, but there are other possibilities which must be considered in any discussion of the ultimate source of the oil in these fields. The Monterey shales are much thicker and far more organic than the usual type of Eocene shale seen in the outcrop, and they are known to be the source of large quantities of oil not only in Ventura County but also in many other parts of California. From scattered outcrops along the northern front of Oak Ridge and South Mountain it is known that the Monterey is in faulted contact with the Sespe, the fault being a high-angle thrust. It is therefore quite possible that the oil in these fields may have originated in the Monterey and migrated into the Sespe sands across the fault.

The Ventura Avenue field is on the same line of uplift as the fields just mentioned but it differs from them in many respects. The structure is similar, but the productive horizons are in the Fernando, many thousands of feet above the Sespe oil horizons. The oil, which is like the Sespe oil from the fields south of Santa Clara River, is unquestionably derived from the organic Monterey shales below the oil-bearing Fernando sands. Thus the Ventura Avenue field offers some support to the hypothesis that the Sespe oil in the Oak Ridge–South Mountain fields might also have been derived from the Monterey.

In the third group fall the Simi or Tapo Canyon, Scarab, and Camarillo fields in the southeastern part of the county. In the Simi field a small amount of oil is obtained in the Tejon and Meganos formations, a short distance below the base of the Sespe. In the western part of the field thin lenticular oil sands are found near the base of the Sespe. The oil occurs in a rather sharp, westward-plunging anticline. The width of the productive area is barely a quarter of a mile. The gravity of the oil is unusually high, averaging between 35° and 36° Baumé. In this field the original source of the oil is in the Meganos shales which are exposed a short distance to the east.

The Scarab field includes four or five scattered wells north of Simi Valley and 5 miles west of the Tapo Canyon field. This region is on the north flank of the Simi anticline about 1½ miles north of, and several thousand feet stratigraphically above, the crest. Here there are several outcropping oil sands high up in the Sespe, which dips uniformly to the north. The present production from this area is negligible.

The Conejo field, at the foot of the Conejo grade, is one of the most unusual in California as the oil is obtained from basalt agglomerate. The only rocks exposed in the vicinity of the field belong to the upper part of the Conejo volcanics, which here consist of flows of basalt and andesite, and coarse volcanic agglomerate. The latter, which is the most abundant type, is made up of large angular blocks and small fragments of basalt inclosed in a matrix of basalt or basaltic tuff. These volcanic rocks form the steep hills southeast of the town of Camarillo and also underlie the small alluvium-

filled valleys within and along the front of the hills. The structure is simple, the dip being uniformly to the north at angles of 20°–28°; the strike is N. 60–70 E.

The occurrence of oil in this region is unusual for three reasons: one is the fact that the reservoir rock is sheared basalt, basalt agglomerate, or alluvium overlying these rocks; another is the very shallow depth at which the oil is encountered, 60–250 feet; and the third is that structure apparently plays little part in the accumulation.

TABLE I

Field	Formation	Type of Structure	Daily Production
			bbls.
Ventura Avenue	Lower Fernando	Dome	4,400
South Mountain	Sespe	Dome	4,000
Montebello	Sespe	Dome	1,000
Torrey Canyon	Sespe	Dome	250
Bardsdale	Sespe	Dome	75
Modelo	Monterey	Sharp plunging anticline	75
Simi	Tejon and Sespe	Plunging anticline	
Scarab	Sespe	Limb of fold	
Conejo	Conejo volcanics	Fault	
Sulphur Mountain	Monterey	Fault	300
Ojai	Monterey and Sespe (?)	Fault	
Sespe Creek	Sespe	Fault	
Hopper Canyon	Monterey	Sharp folds	
Total			10,100

Not far north of the field the Conejo volcanics are in faulted contact with the Tertiary sediments, and it is probably along this fault that the oil rises into the volcanic rocks. There are three possible sources for the oil: (1) it may have originated in the Eocene shales below the volcanics; (2) it may have migrated into the fault, and thus into the volcanics, from sands in the Sespe; (3) or it may have come from organic shales interdigitated with the flows and agglomerates. There is no direct evidence as to which of these hypotheses is correct. Small amounts of oil have evidently moved upward along the somewhat porous agglomerates and accumulated in the alluvium which overlies them in the shallow valleys at the edge of the hills. There is no gasoline in the oil, which has a gravity of 16° Baumé. The average production is about one-fourth of a barrel per well per day.

There are three general modes of occurrence of oil in Ventura County: (1) on the crests of closed domes; (2) along faults, or in sharply folded beds associated with faulting; and (3) from oil sands which crop out on the limbs of large folds. Of these the most important mode of occurrence is the first, since fully 98 per cent of the present production comes from fields on closed domes.

Table I shows the production by fields, the beds in which the oil occurs, and the type of structure.

II. THE SOUTH MOUNTAIN OIL FIELD

F. S. HUDSON

INTRODUCTION

In the preceding section of this paper Mr. Taliaferro has presented the salient features of the geology of the Ventura County oil fields. This and following sections of the article give a more detailed description of the important South Mountain and Ventura Avenue fields. These fields have been chosen as examples of the occurrence of oil in this region because they are by far the largest in productivity of any of the coastal fields lying between the Los Angeles Basin to the southeast and the Santa Maria fields to the north. In addition to their economic importance, these fields exhibit many features of both geologic and engineering interest, and furnish examples of some conditions and problems which are unique.

Location.—The South Mountain field is 4 miles southeast of Santa Paula, a city in the Santa Clara Valley, 70 miles by road northwest of Los Angeles. Rail transportation is furnished by a branch of the Southern Pacific Railroad, which passes through Santa Paula, forming a connecting link between the "Coast Line" at Ventura and the "Valley Line" at Saugus.

Topography.—The most prominent peak along the western part of the Santa Susana–Oak Ridge Range is South Mountain, whose highest summit has an elevation of 2,350 feet above sea-level. The South Mountain oil field lies on the rugged north flank of this mountain, in a region of sharply incised canyons. The average elevation of the productive field is about 900 feet above sea-level, or 500 feet above Santa Clara River, which skirts the foot of the

mountain, whereas the difference in elevation between the lowest and highest wells is more than 700 feet, in a horizontal distance of only 1,400 feet.

History and methods of development.—The South Mountain field is the youngest, in point of discovery, of the fields along the Oak Ridge zone of anticlinal uplift. Attention was directed to the possibility of finding oil in this field as early as 1909, when leases were obtained from some of the landowners. However, drilling was not commenced until 1915, and production of oil in commercial quantities began in 1916. The following table gives, in round numbers, the yearly production to date, and also the number of wells producing at the end of each year.

TABLE II

Year	No. of Wells	Production
		bbls.
1916	2	2,000
1917	8	67,000
1918	12	347,000
1919	17	643,000
1920	24	953,000
1921	33	1,211,000
1922	41	1,432,000
Total to end of 1922		4,655,000

The extremely rugged nature of the country in which this field is situated renders development difficult. It has been found that careful engineering work is of the utmost importance, as a change of but a few feet in the course of a road or the location of a rig grade may mean a difference of several thousand dollars in the cost of construction. In certain places it has been found economical to dispense with roads and provide tramways for transportation of materials to and from well sites. A discussion of the engineering problems in this field and their solution will be found in a recent paper by W. M. Jones.[1]

All attractive acreage in the South Mountain field is controlled by two companies, and, for this reason as well as the fact that the

[1] "Unusual Engineering Problems in the Development of the South Mountain Oil Field, Ventura County," *California State Mining Bureau, Summary of Operations*, Vol. 7, No. 12, June, 1922.

wells do not yield spectacular flush production, the development of the field has not been rapid. A peculiarity of the field lies in the large number of separate, productive sands. In the central part of the field it is not uncommon to find an aggregate of from 900 to 1,800 feet of oil sand between the depths of 500 and 3,500 feet.

Drilling has been done entirely with cable tools. The general practice is to drill a large open hole to the top of the first oil sand, cement 12½-inch casing to shut off the top water, and then continue drilling, carrying 10-inch casing close behind the tools. There are no intermediate waters in the central portion of the field, and the various strings of 10-, 8¼-, and 6¼-inch casing are landed as necessity dictates. It is generally possible to finish the wells to a depth of 3,500 feet or more, with 6¼-inch casing. It is sometimes necessary to run in a string of 15-inch casing to protect the 12½-inch string against caving formations. The larger casing can generally be recovered after the 12½-inch string has been landed.

Power for drilling is obtained from steam, generated by burning residual gas from the casing-head gasoline plant. Power for pumping is obtained from steam, or directly from gas in gas engines. Electric motors have been found more economical than gas engines for pumping wells, but they are considered dangerous, due to the presence of heavy flows of natural gas. Electric power for drilling has not been used in the South Mountain field, but has been employed successfully in drilling prospect wells in other parts of the county.

GEOLOGY

Two of the major divisions of the Tertiary formations of California are exposed in the South Mountain field—the Sespe series, of Oligocene or Lower Miocene age, and the Monterey series, of Lower and Middle Miocene age. An older series of rocks, of Eocene age, is probably present, underlying the Sespe beds. An intrusive igneous rock of Lower Miocene age completes the geologic sequence in this field.

Eocene.—The nearest localities to the South Mountain field at which Eocene rocks are exposed are in the Sespe Creek region, 10 miles to the northeast, and in the Simi region, about 20 miles to the east. In the latter locality the Eocene consists of 2,000–4,000 feet

of sandstone, sandy shale, and dark clay shales of marine origin. In the Sespe Creek region the Eocene has much the same appearance as in the Simi region, but contains a much greater proportion of sandstone.

Many seepages of oil are known to issue from the Eocene beds in the Sespe Creek region. The oil of the Tapo field in the Simi Valley region occurs in sandstone in the upper part of the Eocene section and is thought to have had its source in the underlying shales. The Eocene formations must therefore be considered as one of the possible sources of oil in the South Mountain field.

Sespe series.—In the region of South Mountain the Sespe series includes over 6,000 feet of sandstone, clayey sandstone, and shale. This great thickness of beds is a typical "red bed" series, and, from its lithologic character and the lack of remains of marine organisms, it is believed to be of non-marine origin. The sandstones of the Sespe in this field are typically gray in color, weathering to buff, but some maroon sands occur. The clayey sandstones are maroon, due to the color of their clayey constituents. The shales are typically maroon, though sometimes of a brighter red color. Beds of "sticky" blue shale such as are found in other Tertiary formations of California occur here, but much of the "blue shale" reported in logs of wells is in reality a fine-grained, greenish sand, which may be seen in the outcrop as thin layers, inclosed in red shale or clayey sandstone.

The following section is compiled from evidence of outcrops and well data in the South Mountain field:

	Feet
Upper Sespe: Gray and greenish-gray soft sandstone, with layers of red clay shale in minor amount	650
Middle Sespe: Soft, yellow-weathering, massive sandstones, often conglomeratic, separated by alternating gray sandstone, red clayey sandstone, and green and red shale. On the basis of lithology the Middle Sespe is divided as follows:	
Sandstone No. 1 (upper member of Middle Sespe). Massive, yellow-weathering, arkose sandstone, often conglomeratic, containing bowlders up to 8 inches in diameter	150–275
Intermediate red beds. Alternate layers of red sandy shale and gray sandstone, in about equal proportion, with minor amounts of green clay shale	250–350

Sandstone No. 2. Heavy, yellow, conglomeratic sandstone, with a few thin, red partings..... 100–220

Middle Sespe oil measures. Alternating layers of red clay shale and sandy shale, blue-gray clay, and gray sandstone. At South Mountain it has been exposed by erosion..... 200–400

Sandstone No. 3. Similar to sandstones Nos. 1 and 2..... 80–250

Lower Sespe: The Lower Sespe consists of alternating layers of red sandy shale, red clayey sand and gray sandstone, and blue-gray shale. The well logs generally report the Lower Sespe shales as "brown shales." They are, in fact, of a brownish color, but always have a reddish cast, so as to be really maroon. These "brown shales" are not to be confused with the brown shales of the Monterey series found in other California fields which are gray-brown, yellow-brown, or chocolate-brown, but never maroon. No well has as yet reached the bottom of the Lower Sespe in the South Mountain field, and the thickness of this member is thus known to be at least..... 4,000

Monterey series.—In the South Mountain region this series overlies the Sespe beds with apparent conformity, but the contact of the Vaqueros sandstone of the Monterey series with the underlying Upper Sespe sandstone can be distinguished by a change in lithology and the appearance of marine fossils.

The lower member of the Monterey series, the Vaqueros formation, is a body of soft, gray, medium-grained, arkose sandstone, having a thickness of 350 feet in the southwestern portion of the field and increasing in thickness, easterly, to some 600 feet.

The shale member of the Monterey series overlies the Vaqueros sandstone conformably, and consists of about 1,250 feet of hard, white, porcelaneous, siliceous shale, together with soft, siliceous shale and minor amounts of tuffaceous shale. These shales all contain a certain amount of organic material and, in part, are so high in hydrocarbons that they burn readily to a slightly fused porous rock, colored red and black by iron and manganese oxides.

Dacite intrusions.—The north slope of South Mountain, in the region directly south of the oil field, is quite steep, and near its summit are high cliffs. The slopes beneath the cliffs are cut in the easily eroded Upper Sespe, whereas the cliffs are composed of intrusive igneous rock together with that portion of the overlying Vaqueros sandstone which has been indurated by the effects of the intrusion.

The igneous rock is a dense, fine-grained dacite, blue-gray in color, which has been intruded along the contact between the Sespe and Vaqueros beds as a sill, the maximum thickness of which is 225 feet. The lower contact of the sill is generally obscured by talus, and, where exposed, is at an inaccessible part of the cliff. The upper contact, however, can be examined at several localities and exhibits the phenomena of an intrusive contact, including stoping of the roof material.

No igneous rock has been found within the oil field either in outcrops or in the wells, but there is another intrusion of dacite on the extreme north flank of the anticline, where it occurs as an irregular dike, cutting steeply tilted Sespe beds.

Landslides and talus.—Thick, widespread accumulations of recently deposited detritus mantle the slopes north of the steep escarpment of South Mountain. This material is made up of angular fragments of the volcanic rock, with minor amounts of the hardened Vaqueros sandstone and of the harder varieties of Monterey shale. Some of these detrital masses are landslides, consisting of fractured bodies of volcanic rock that have moved bodily down the steep slopes from the cliffs. Another portion of the material is made up of blocks of various sizes that have individually rolled down from the steeper slopes to their present resting-place. The greater part of the talus-mantled area is still receiving accretions from the cliffs of South Mountain, but there are other masses capping hills immediately south of Santa Clara River which have been isolated from the main mass by the recent erosion that has carved the deep canyons of the region.

STRUCTURE

The South Mountain oil field is situated on one of a series of five domed uplifts that lie along the north flank of the Oak Ridge–South Mountain range. These domes are, named in order from west to east: the South Mountain, Bardsdale, Montebello, Wiley Canyon, and Torrey Canyon domes. Each of the domes is a structural unit, that is, their axial lines are not continuous, the domes being arranged *en échelon*, so that each successive dome to the west lies farther south than its eastern neighbor.

South Mountain dome.—In general the South Mountain dome may be described as an elongated, domed uplift, the major axis of which trends east-west. From the point of greatest uplift the axial plunge to the west is gentle, reaching a maximum of 12° at a distance of 1 mile. To the east of the domal crest the axis plunges at a low angle for the first half-mile, and then increases rapidly to a maximum of 25° at 1 mile from the crest.

The central portion of the dome is made up of two parallel anticlinal flexures, separated by a very shallow synclinal depression, the whole forming a broad, almost flat, crest 2,000 feet in width. On the north flank of the dome the dip increases gradually from 4° to 30° in the first quarter-mile, beyond which the increase is more rapid, until at a distance of 3,000 feet the beds are overturned, so as to dip south at high angles. On the south flank of the dome the dip increases gradually to a maximum of 60° in a distance of three-quarters of a mile from the southerly crest.

Santa Clara fault.—The narrowest part of the Santa Clara Valley is immediately east of Santa Paula. Here on the south side of the valley are steeply dipping beds of the Middle Sespe. On the north side of the valley, opposite this point, are beds of the Fernando group which dip gently to the south, beneath the valley. These beds probably represent the Saugus formation, the upper part of the Fernando group, and are underlain by fully 5,000 feet of Pliocene strata. Beneath the Fernando lies the Monterey series, which is here fully 2,500 feet thick, and the Upper Sespe, which, where exposed on the south side of the valley, has a thickness of about 1,000 feet. The stratigraphic difference between the two sides of the valley is the sum of the thicknesses of the Fernando, Monterey, and Upper Sespe, which is fully 8,500 feet. The horizontal distance across the valley here is but 8,200 feet and, even were the rocks standing vertically, 8,500 feet of strata could not be crowded into this space. Thus it seems certain that a fault, or zone of faulting, exists somewhere beneath the Santa Clara Valley. Along this fault there must have been a relative depression of the Fernando rocks on the north with respect to the Sespe rocks on the south. The exact position of this fault cannot be determined, due to the alluvial cover of the valley, but it is believed to lie not far north of the south

limit of the valley, that is, near the south channel of Santa Clara River. It is proposed to call this break the Santa Clara fault.

In the region extending from Willard Canyon for 1 mile west, the upper members of the Middle Sespe have been overturned, so as to dip steeply southward, although they lie on the north limb of the South Mountain dome. From this evidence it is concluded that the Santa Clara fault is a reverse fault, dipping southward. A study of the well logs of the South Mountain field leads to the conclusion that the dip of the fault plane is rather steep, probably about 60°.

A parallel fault, of similar reverse type, lies about 1,000 feet south of the supposed position of the Santa Clara fault. The evidence for this fault is clear. It is considered to be a minor fault, subsidiary to the major one.

Faulting within the oil field.—There are several minor faults known to occur within the field, the amount of movement on which is, perhaps, nowhere over 50 feet. Two faults, apparently of much greater importance, are known to occur in the eastern part of the field, trending northeast, obliquely across the axes of folding. Due to the presence of a cover of talus throughout this part of the field, enough evidence has not been obtained to make exact measurements of the character and amount of movement along these faults. However, it may be said that the fault planes dip southeastward, that the horizontal component of displacement is probably fully as great as the vertical component, and that, in the eastern of the two faults, the movement has been downward and northeastward on the southeast side of the fault plane.

OCCURRENCE OF OIL

The oil of the South Mountain field is produced from a large number of sands of the Lower Sespe formation. The Middle Sespe oil measures, which yield the shallow oil in the Montebello field, have been removed by erosion from the summit of the South Mountain dome.

Oil zones.—In the accompanying structure section (Fig. 2) the oil measures are shown by the "oil zones," outlined in solid black. The term "oil zone" is used to indicate, not a continuous sandstone bed saturated with oil, but a series of alternating oil sands and barren

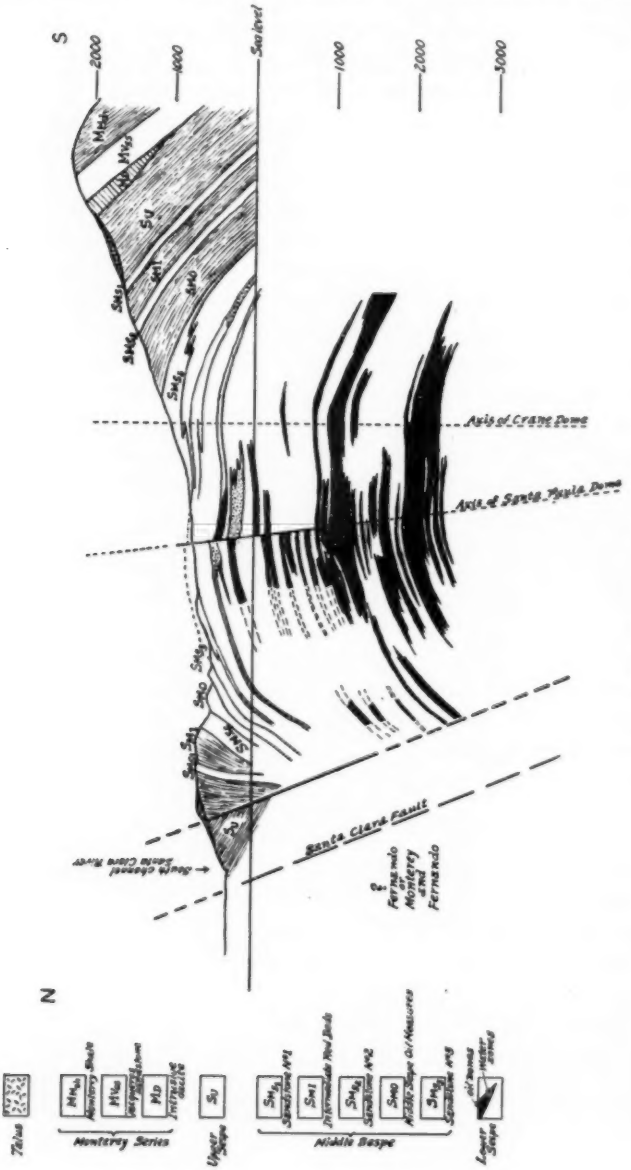

S
2000
1000
Sea level
1000
2000
3000
Axis of Crane Dome
Axis of Santa Paula Dome
Santa Clara Fault
South Channel Santa Clara River
Structure Section through South Mountain Field
0 1000 2000 FEET
By F S Hudson
N
Talus
Monterey Series
Upper Sespe
Middle Sespe
Lower Sespe

FIG. 2

layers, in which the oil-bearing portion makes up from 30 to 100 per cent of the whole. Due to the large number of separate sands and also to their discontinuous nature, exact correlations between the sands of even closely adjacent wells are impossible. It has been found, however, that certain of the oil zones are rather persistent throughout the field.

Extent of the zones.—As in most other oil fields of California, the upper oil zones here are productive under a smaller area than are the deeper zones. In that portion of the field underlain by productive shallow sands, it is generally necessary to cease drilling at 2,500–3,000 feet, place the well on temporary production and finish the well to deeper sands after the gas pressure of the upper sands has been considerably reduced.

The extent of the field on the east, north, and west sides cannot yet be definitely fixed. To the south, the limit of commercial production, for sands discovered to date, appears to be at about 3,000 feet from the main crest of the dome.

SOURCE OF THE OIL

It has been mentioned previously that the marine shales of Eocene age, which probably underlie the Sespe beds in the South Mountain field, are a possible source of the oil produced there. There are two other possible sources.

Eocene source.—There can be little doubt but that the Eocene beds underlie the Sespe series in this field. Marine shales of the Eocene are probably the source of the oil produced in the Tapo field, 20 miles east of South Mountain, and numerous seepages of oil are known to issue from the Eocene formations to the north of the Santa Clara Valley. The Eocene shales must then be considered a potential source of oil, wherever they occur, and if they are present beneath the Sespe in the South Mountain field, oil formed from the shales may have migrated across the bedding of the Sespe, or perhaps have risen upward along the Santa Clara fault, and become concentrated in the sands of the Sespe where it is now found.

Sespe source.—Nowhere in any of the sections of the Sespe series, which have been studied in the outcrop or by means of drill cuttings, has any material been found which, according to our present ideas

of the origin of oil, could be considered as a possible source. Although it is probable that the Sespe rocks were accumulated in an inland basin, cut off from the sea by land barriers, it is quite possible that, even if the Sespe which we now see was deposited above sea-level, its basin of accumulation was not separated from the sea by land barriers. In either case there must have been deposition of marine formations during the same period of time in which the non-marine Sespe was being deposited, and, if no barrier separated the Sespe Basin from the sea, then the land-laid Sespe beds must grade laterally into beds of marine origin.

Such marine beds of Sespe age may be everywhere buried beneath later deposits, or, on the other hand, they may be exposed in some parts of the state, having there been given some other formational name. In any event, if the Sespe of South Mountain does grade laterally into marine beds, which lie beneath the Oxnard plain, or beneath the Santa Barbara Channel, these marine beds doubtless include organic shales which could readily furnish oil to the South Mountain field by migration up the dip into the sands of the non-marine Sespe. In this connection it may be noted that Oligocene organic shales are present in the Coalinga region, and are thought to have been the source of much of the oil in that field.

Monterey source.—Organic shales of the Monterey series are believed to be the source of the oil produced from reservoirs in the Monterey and overlying Pliocene rocks in many oil fields of California. Although the Monterey shale is stratigraphically above the Sespe series, yet in the South Mountain field it is highly probable that the movement along the Santa Clara fault has brought the Sespe beds on the north flank of the dome to a position structurally above the Monterey beds. Oil formed from the organic shales here may then have migrated upward and across the fault into the Sespe sands.

While objection may be raised to this theory, on the ground that the oil of this field is dissimilar to that of Monterey origin obtained in many other fields, it may be said that the oil of South Mountain has many characteristics in common with that of the Ventura Avenue field, where the oil, almost certainly, was derived from the Monterey shales.

III. THE VENTURA (AVENUE) FIELD

W. N. CRADDOCK

GEOLOGIC FORMATIONS

The formations involved in the Ventura anticline are included in the Fernando group of marine Pliocene age (Fig. 3). An unconformity exists in the Fernando, although not positively recognized in the vicinity of Ventura, and is the basis of a division of the group into two formations, the upper being called Saugus and the lower, Pico; the two formations including, in the vicinity of the Ventura field, approximately 15,000 feet of unconsolidated sediments. A complete section of the Fernando is not exposed along the Ventura anticline; the top of the Saugus is incomplete and the lower part of the Pico, where exposed, is faulted against Miocene strata. Development in the Ventura field has been in the Pico formation, the Saugus-Pico contact being 2,000 feet or more stratigraphically higher than the beds exposed in the heart of the field.

The explored formation consists of unconsolidated, coarse- to medium-grained, arkose sands, together with sandy shales and a lesser amount of bluish-gray to brown shale frequently containing Pliocene foraminifera. Correlation of the strata from well logs is exceedingly difficult, there being no distinctive color horizon or other characteristic marker. The best marker is the Gosnell shale zone, a fairly uniform stratum approximately 3,000 feet deep, which varies in thickness from 200 feet to 75 feet and contains varying amounts of sandy shale and sand. These sands are frequently gas-bearing. The base of the shale zone is more easily recognized than the top, the lower 25 feet or more being shale practically free from sand. The lithological character of this shale is not unlike other shales logged in the field, but because of its being the most persistent and uniform shale body recognized in the well logs, it affords the best means of correlation. The Gosnell shale is usually underlain by oil and gas sands, which aid materially identification of the base of the Gosnell shale.

Above the Gosnell shale zone the well logs show no characteristic strata. Coarse sands predominate and correlation of these beds from their lithological character is practically impossible. Below

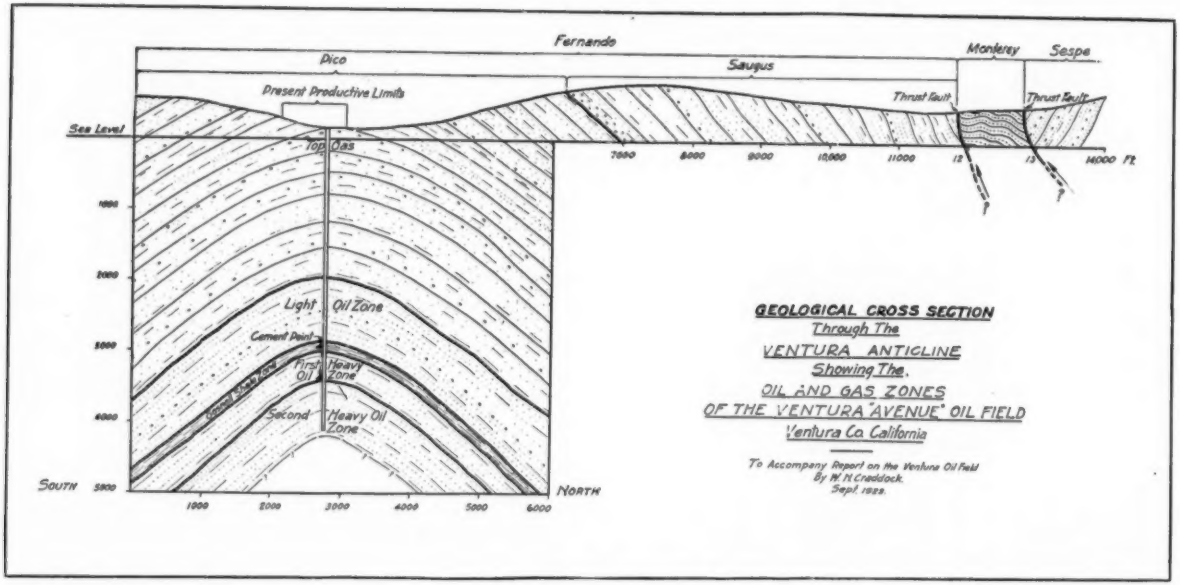

Fernando
Pico
Saugus
Monterey
Sespe
Present Productive Limits
Thrust Fault
Thrust Fault
Sea Level
Top Gas
7000
8000
9000
10,000
11000
12
13
14000 Ft.
1000
2000
3000
4000
5000
Light Oil Zone
Cement Point
First Heavy Oil Zone
Second Heavy Oil Zone
SOUTH
NORTH
1000
2000
3000
4000
5000
6000
GEOLOGICAL CROSS SECTION
Through The
VENTURA ANTICLINE
Showing The
OIL AND GAS ZONES
OF THE VENTURA "AVENUE" OIL FIELD
Ventura Co. California
To Accompany Report on the Ventura Oil Field
By W. N. Craddock.
Sept. 1923.

FIG. 3

the Gosnell shale the strata consist of alternating medium-grained sand, sandy shale, and shale. Here, too, correlation of the strata is exceedingly difficult, due to their thickening and thinning and their great variation in lithologic character within comparatively short distances.

STRUCTURE

The Ventura field is located on the structurally highest part of the Ventura anticline, a sharp, well-defined fold with average dips on the flanks of from 30° to 45°. The anticline is traceable for a distance of approximately 17 miles in a general east-west direction from the Santa Clara River Valley, 9 miles east of the field, to the Pacific Ocean, 8 miles to the west. The trace is concave to the north, reflecting in a general way the dominant structural features of the vicinity—a series of anticlines and synclines accompanied by thrust faulting. The greatest flexure in the trace is at a point approximately 1½ miles west of Ventura River. To the west of this point the trace bears N. 68 W., whereas to the east the trend is N. 83 E. West of the field the anticline plunges gently, but on the east it has a steeper plunge, gradually increasing to 20° where it passes under the Santa Clara Valley alluvium.

The fold is not in every place symmetrical, and is strongly asymmetric east of Ventura River where the north flank is the steeper for a considerable distance. On the sides of the Ventura River Valley, the surface dips show the structure to be practically symmetrical. Where incoherent beds are sharply folded, as in the Ventura anticline, the subsurface axis in all probability does not coincide with its surface trace, which condition greatly increases the hazards of exploratory drilling.

OIL MEASURES

There are two distinct oil zones which are separated by the Gosnell shale zone: (1) the light-oil zone (upper) contains oil varying in gravity from 47° to 56° Baumé, and consists of approximately 1,000 feet of unconsolidated strata, capable of producing probably not more than 200 barrels per day of light oil and at least 1,500 barrels per day of salt water; and (2) the heavy-oil zone (lower), which contains oil varying in gravity from 28.5° to 30.8° Baumé and a small amount of 39° Baumé oil in the uppermost sands. The

heavy-oil zone includes the total explored strata below the base of the Gosnell shale, a thickness of approximately 1,200 feet. Neither zone is a uniform, single stratum of oil sand. The heavy-oil zone has lean and even barren strata, as a rule shale or sandy shale, but they are not always continuous for even a comparatively short distance.

A further division has been made of the heavy-oil zone into (*a*) first heavy-oil zone, comprising approximately 400 feet of strata capable of producing approximately 150 barrels per day of 30° Baumé oil and an unknown quantity of water, probably not more than 30 barrels per day, and (*b*) second heavy-oil zone, which includes the strata below the first zone producing as much as 1,900 barrels per day of 30° Baumé oil. Wells producing from this zone have yielded water varying in quantity up to 100 barrels per day. So far as can be determined from information at hand, there is no water sand or a definite barren stratum separating the two heavy oil zones, but the separation is based mainly upon their relative productivity. It has been found impractical to produce from the first zone, which is now mudded and cased off.

Two barrels of oil per day of 41° Baumé have been produced from the lower 100 feet of the light-oil zone, and 39° Baumé oil has been encountered in small quantities just below the base of the Gosnell shale, or at the top of the first heavy-oil zone.

Light-oil zone.—The light-oil zone, consisting chiefly of coarse-grained, unconsolidated sands with a small percentage of sandy shale and shale, extends from a depth of approximately 2,000 feet at the structurally highest part of the field, to the top of the Gosnell shale zone. The total thickness is probably saturated with gas under extremely high pressures and contains discontinuous bodies of 47°–56° Baumé oil.

Production from the entire zone has never been obtained by any one well; the largest production was 100 barrels of oil per day from the upper part of the zone. There is at least one water sand in this zone which is about 500 feet above the base of the Gosnell shale, and this has yielded as much as 1,500 barrels per day. This sand, as well as sands above the light-oil zones, have probably flooded the entire productive measures.

Heavy-oil zones.—Approximately 400 feet of alternating medium-grained sand, sandy shale, and shale comprise the first heavy-oil zone. Production from these strata, during the earlier stages of the field's development, was unsatisfactory, due to the low yield of oil and the large amount of water which was produced because of the failures to shut off the water from above the Gosnell shale. The maximum production obtained from this zone was from the Gosnell No. 1 well of the Shell Company of California, which produced an average of 135 barrels of oil per day for over a year, together with 400 barrels of water per day. The large production of water was due to a shut-off failure in the Gosnell shale.

This zone has probably been damaged to some extent by infiltrating water, there being evidence that these sands originally contained less than 30 barrels per day of water. At present there is no production from this zone, as the wells originally producing from these strata have been redrilled and deepened. The more recent practice is to protect the oil sands by mudding and cementing a string of casing at the base of the zone as well as cementing in the Gosnell shale overlying the zone.

A sand containing a small amount of 39° Baumé oil occurs at the top of this zone in three wells.

The field's entire production, with the exception of approximately 50 barrels per day from the light-oil zone, now comes from the second heavy-oil zone. This zone, a series of sand, shale, and sandy shale—sand predominating—includes the total explored strata below the first heavy-oil zone. It aggregates approximately 1,200 feet in the deepest well, the Associated Oil Company's Lloyd No. 6. The lower limits of the zone are unknown.

It is difficult to correlate the individual strata of one well with another, for there appears to be considerable variation in the lithologic character of the beds as well as in their fluid content. One well came in with 939 barrels of oil, but another well, 500 feet distant and with the same sands screened, has never made more than 150 barrels of oil per day. The largest production yet obtained from this zone was 1,900 barrels per day, which declined in ten months to 600 barrels per day.

Wells producing from this zone make as much as 120 barrels of water per day, which declines in quantity at approximately the same rate as the oil. It is possible that there has never been a complete separation of the oil and water into individual sands separated by impervious strata; also the water may occur in more or less lenticular zones so that a well may encounter all or only a part of the maximum amount of water within the zone.

SOURCE OF OIL

The following theories as to the source of oil in this field have been advanced: (1) the oil originated in the Meganos organic shale (Middle Eocene); the Monterey group (Miocene) and Sespe formation (Oligocene?) which were subsequently deposited and uplifted were eroded, the Fernando (Pliocene), into which the oil migrated, being deposited on the eroded surface of the Eocene and folded into the present anticline. (2) Oil which originated in the Meganos organic shales migrated upward along the thrust-fault plane, approximately 2 miles north of the field, and entered the various horizons in the Fernando. Although the Monterey is in contact with Fernando beds at the surface along this fault, it is probable that the Eocene beds are in contact with the Fernando below the surface. (3) The oil originated in the Monterey organic shale (Miocene) and afterward accumulated in the unconformably overlying Fernando beds—the oil becoming increasingly lighter during the process of upward migration. (4) The oil originated in organic shales within the Fernando and accumulated in the adjacent or overlying sands, the lighter constituents accumulating, according to their densities, in the higher strata of the anticline.

DEVELOPMENT

The discovery of gas seepages coming up through the water of an irrigation ditch which crossed the structure just east of Ventura River led to the drilling of shallow wells and the discovery of the top gas zone in 1903. Ten shallow wells, the deepest being 800 feet, were drilled for the purpose of producing gas. Seven of these wells which were drilled within a small area just north of the crest produced an average of 13,000,000 cubic feet of gas per day, and an average of one barrel per day of 56° Baumé oil. The most

prolific sands occurred from 300 to 400 feet. The large amount of water, which was present in all the wells, could not be shut off, and considerable difficulty was experienced in drilling through the surface bowlders with the light portable percussion type drilling rigs. The supply of gas, however, was sufficient to warrant the laying of 20 miles of 2½-inch line to supply the nearby towns of Ventura and Santa Paula.

In 1915 the State Consolidated Oil Company in exploring below the top gas zone encountered a small amount of 50° Baumé oil at 2,250 feet in its well, Lloyd No. 1. Subsequently other wells were drilled into the light-oil zone, but due to the difficulties experienced in shutting off water from above, and in locating and properly casing off water sands within the zone, the oil measures were soon flooded.

The most extreme difficulties were experienced in attempting to produce from this zone. There is no continuous stratum of clay or shale to afford a suitable place for cementing off the large flow of upper waters, and there is at least one water sand within the zone. To obtain commercial production from the entire zone without opening up the water sands is impossible, for the individual oil sands are lenticular. An added difficulty in cementing in any part of the zone is the enormous amount of gas. One well, upon entering the top sands of the zone, blew out, destroying the rig and subsequently forming a crater 100 feet in diameter at the surface. Another well, after being drilled to the bottom of the zone, blew out and later, after the rig had been pulled down, the flow of mud, water, oil, and gas broke through behind the casing and formed a crater. This well, however, was being drilled to produce from the heavy-oil zone, but it serves as an example of the hazardous drilling conditions. One of the early wells, upon reaching a depth of 1,368 feet and being shut in, flowed mud, water, and gas at the surface at a distance of 400 feet from the well.

The next important stage in the field's development was the Shell Company's discovery of sands containing 30°–39° Baumé oil in the upper part of the first heavy-oil zone. Here, also, great difficulty was experienced in shutting off waters from above. However, advancement in cementing methods and a better understanding of

local conditions have, to a large extent, overcome this trouble. Wells which produced from this zone are usually small, which was discouraging because of the comparatively heavy cost of drilling.

The discovery of more productive sands below the first heavy-oil zone led to the uniform practice of cementing a string of casing at the base of this zone, after protecting the cased-off sands from infiltrating water by pumping in mud fluid prior to cementing. At present there are 15 wells producing an average of 290 barrels of oil and 30 barrels of water per day from this zone. The average gas production is approximately 500,000 cubic feet per day per well.

Development has been confined to an area approximately 1 mile long and $\frac{1}{8}$ mile wide extending along the crest of the anticline.

DRILLING METHODS

Both the cable tool and rotary method of drilling have been used with equal success. The rotary method has been more generally used during the past two years, although, even with improved rotary methods, there will undoubtedly continue to be considerable cable-tool work in this field.

Although this field has not the volume of gas reported in other California fields, it is exceedingly difficult to keep the wells under control while drilling. One rotary hole had to have heavy mud (90 lb. per cu. ft.) circulated for over a week before the drill pipe could be pulled out. A blow-out preventer is used in packing off between the casing and drill pipe.

While drilling through the oil zones with cable tools, the wells are packed off between the casing that is being "carried" and the last string that was landed or cemented. By means of an oil-saver or circulating head through which the drilling cable is run, the well can be entirely shut in, or can be circulated while drilling. The gas pressure is so strong that a well, even after being thoroughly mudded, will remain "dead" but a few hours. The best results have been attained in cable-tool holes by continually circulating mud while drilling, allowing the well to flow behind the casing through a restricted orifice when oil and gas sands are encountered. By so doing the casing is less likely to become frozen by the mud that is pumped in.

PRODUCTION

The following table gives the oil and water production of the Ventura (Avenue) field by years since 1918:

TABLE III

Fiscal Year	Oil (Bbls.)	Grav.	Waters (Bbls.)	Average No. of Wells Producing	Average Barrels Oil per Well per Day	Average Barrels Water per Well per Day
	Light-Oil Zone					
Ending June 30, 1918...	9,119	52.0	103,516	2	12	142
1919...	13,528	52.0	143,353	2	18	196
1920...	6,095	50.0	90,266	2	8	124
1921...	14,965	50.0	263,581	2	20	361
1922...	12,545	49.0	379,043	2	17	519
1923...	18,811	49.0	461,788	3	17	422
	Heavy-Oil Zone					
Ending June 30, 1918...	.....	.....	.....	.....	.....	.....
1919...	17,786	29.0	75,332	1	49	206
1920...	64,928	29.0	147,395	1	178	404
1921...	124,608	29.0	256,561	5.7	60	123
1922...	236,439	29.0	65,104	5.7	114	31
1923...	1,205,320	29.0	190,174	11.5	287	45
Total.....	1,724,144	.....	2,176,113	.....	.....	.....

GEOLOGICAL NOTES

"DIRECT SYNTHESIS OF HIGHER FROM LOWER HYDROCARBONS"[1]

In the issue of *Science* for October 17, 1924, there is an article under the above title calling attention to very interesting experimental results obtained by S. C. Lind and D. C. Bardwell, of the U. S. Bureau of Mines. Attention has been called to the occurrence of vanadium and nickel in petroleum by DeGolyer on page 550, Volume 19, of *Economic Geology*, and by Ramsey's paper abstracted by Hess in this *Bulletin*. Wells has also submitted additional observations on the minor constituents of petroleum for publication in *Economic Geology*.

The experiment described by Lind and Bardwell consisted of the inclusion of quantities of ethane and of radium emanation in a closed glass vessel sealed by mercury. As a result of continued contact between the two gases, it is reported that by catalytic or other action the ethane was polymerized into octane or some similar member of the paraffin series, probably with the elimination of hydrogen. The exact nature of the product has not been determined, but it clearly belongs higher in the hydrocarbon series than the ethane, with which the experiment started.

As a conclusion it is pointed out that Berthelot many years ago was successful in synthesizing higher from lower hydrocarbons by silent electrical discharge, and Boltwood is quoted as stating that in the experiment by Rutherford and himself it was found that marked alterations were produced in paraffin by exposing it to the action of radium emanation.

These several observations raise most interesting questions as to the possible agency of radio-active materials in the original formation of oil and its possible transmutation from low-grade to high-grade crudes. It would appear entirely possible that there was more than a fortuitous association between the helium present in many oil-field gases and the character of associated oils. Assuming that radium emanations actually are potent in influencing the formation and alteration of oil, interesting speculations may be indulged in as to water movements which might have affected the distribution of radium emanations, and as to the distribution of igneous rocks which might most naturally be regarded as the original source of radium-bearing minerals. Since the time, as well as the volume, factor presumably comes into play in reactions such as those described by Lind and Bardwell, one may imagine that the difference in character of petroleums of different ages may be to some extent explainable on this basis.

[1] Published by permission of the Director, U. S. Geological Survey.

Doubtless there are many members of the Association who have given this subject consideration, and it would be, I believe, both interesting and helpful to the membership in general if ideas on the subject were brought together.

W. T. THOM, JR.

CARBON DIOXIDE FROM WELLS IN COLORADO

The occurrence of carbon in the Farnham and Woodside wells, Utah,[1] are by no means the first examples of their kind in the West. The writer recalls two others. The first of these was on Mustang Creek, Colorado (T. 30 S., R. 51 W.), where a well in the Red Beds encountered a strong flow of carbon dioxide at a horizon I should judge to be the top of the Lykins—possibly of Permian age. A similar occurrence was at a well above Delta, Colorado (T. 15 S., R. 94 W.), which began in the Gunnison formation and struck a heavy flow of gas with salt water at about 300 feet. This well threw spray far above the crown block and there was a continuous roar of escaping gas. The well was then in the top of the Dolores formation. The casing was anchored and the valve closed, but the well blew out in the nearby river and was finally mudded off and drilled on to granite, at about 600 feet.

Both these wells were on anticlinal folds and the gas was associated with salt water. In the case of the Delta well, the salt was first reported as potassium chloride, but turned out later to be mainly sodium chloride. Furthermore, the age of the formations in which the gas occurred was either Triassic or Permian, and the occurrences are very similar to that in the Farnham well. The source of this carbon dioxide is puzzling. In Purgatoire Cañon, the writer observed much leaching of the ferric hydroxide cement of the sandstones in association with mixed gypsum and limestone strata which occur in the Mustang Creek well. This suggests that the carbon dioxide may have originated from the action of sulphuric acid derived from gypsum upon limestone.

The occurrence of carbon dioxide at such widely scattered points as Farnham, Delta, and Mustang Creek indicates that it is due to some general condition in the Red Beds. The association of gypsum, limestone, and salt may be the determining factor. The presence of salt water with the gas suggests a stagnant underground circulation. This must be a determining factor in a gas so readily soluble as carbon dioxide, for it would not long endure in contact with water in active circulation.

JAMES TERRY DUCE

THE TEXAS COMPANY

CORRECTION

Willis Storm, in his article on "Carbon Ratios of Cretaceous Coals in New Mexico," page 524, Volume VIII, this *Bulletin*, erroneously attributed an article on carbon ratios of coals in West Virginia oil fields to Stuart St. Clair. This paper should properly have been attributed to David B. Reger.

[1] Described by W. R. Calvert, this *Bulletin*, Vol. 7, pp. 293–295.

REVIEWS AND NEW PUBLICATIONS

The Minor Oil Fields of Kern County. Summary of Operations, California Oil Fields, California State Mining Bureau, June, 1924, Vol. 9, No. 12.

The June issue of the *Summary of Operations in California Oil Fields* gives a very complete statement of conditions of oil occurrence and production in some important, though small fields in the southern part of the San Joaquin Valley. This article will be found of great importance, not only to operators and geologists, but to all those interested in oil. The fields covered by the report are the Devil's Den, Hovey Hills, Sunset Extension, and Wheeler Ridge, each of which has been prepared by one of the personnel of the State Mining Bureau located in San Joaquin Valley. Each report gives the location of the productive territory, and discusses the history of development, geology, occurrence of the oil, subsurface conditions, technology, and the possibilities for future production in each field. The discussion is supplemented by maps showing subsurface contours of the sands, the areal geology, and the location of all the wells, together with a cross-section of the field. The report on the Sunset Extension Field is supplied with an areal map showing also the topography of the region. The geological departments of several of the more important oil companies have co-operated to a large extent in the preparation of these reports and a considerable part of the data has been derived from this source.

WILLIAM S. W. KEW

The Significance of Nickel in Petroleum. By WILLIAM RAMSAY. *Jour. Inst. Petroleum Technologists*, Vol. 10, No. 41, February, 1924, pp. 87–91.

Since both hydrogen and carbon dioxide occur as natural gases, sometimes in the locality of oil fields, it appeared possible that these gases might form the starting-point for the formation of petroleum. Sabatier and Senderens, by hydrogenating acetylene at high temperature and pressure, not only obtained a liquid corresponding in composition, odor, color, and fluorescence to a natural petroleum, but by varying the conditions as regards temperature, pressure, and concentration, succeeded in synthesizing petroleums of varying characteristics, such as appear in the different oil regions, and they seriously put forward the suggestion that the natural petroleums were formed in a similar manner.

Interesting as Sabatier and Senderens' theory might be, it remained, whilst unsupported by other evidence, only less speculative than those previously advanced, and it occurred to the writer that if their theory is correct, it would be reasonable to expect that the crude natural petroleum might carry to the surface of the earth some trace of the nickel catalyst. On examining the ash of a number of fuel oils from various parts of the world, this was found to be the case. In addition to nickel, many of these oils carry traces of other metals such as vanadium, copper, lead, etc., several of which are also

of catalytic significance. The following table shows the nickel content of a number of authentic petroleums and some associated bodies expressed as parts per million:

Source	Consistency	Ni, Parts per Million
Mexican	Semi-solid	83
Mexican	Thick	49
Mexican	Medium	67
Texas	Medium	44
Texas	Medium	71
Texas	Thin	68
Californian	Medium	49
Californian	Thick	63
Roumanian Ostatki	Semi-solid	17
Persian	Medium	12
Persian	Thin	93
Persian	Thin	4
Burmah	Thin	12
Burmah	Medium	8
Java, Surabaya	Thin	3
Borneo, Balik Pappan	Thin	1
Borneo (Mixed)	Thin	3
Asphalt, Trinidad	.....	194
Asphalt, Swiss	.....	120
Asphalt, rock (unknown)	.....	14
Gilsonite, California	.....	133
Petroleum pitch, U.S.A.	.....	240
Ozokerite (Germany ?)	.....	trace
Ozokerite Refined German	.....	nil

The above oils are the crude petroleums from which the more volatile fractions have been removed by distillation and are known as fuel oils or Diesel engine oils.

So far, all the oils examined have shown the presence of nickel. Those of low viscosity generally show least, and some of the East Indian oils show so little that its presence might easily be overlooked. In some cases, upwards of two kilos. had to be ashed in order to obtain sufficient material for an estimation. One sample of Borneo oil gave less than one part of nickel in 10 million of oil, while a Persian oil in which nickel had been overlooked, showed, on repetition, a quantity much smaller than in the Borneo sample.

At first, the writer was of the opinion that such small amounts of nickel would seriously embarrass Sabatier and Senderens' theory, but Dr. R. Thomas, one of the leading workers in hydrogenation problems, points out that even if oils totally devoid of nickel were found the theory would not be invalidated, since it is now known that very much smaller quantities of the catalyst are required than was previously thought necessary, and in some cases it might be of such a nature that it would be retained in the earth by filtration or sedimentation.

Attempts to ascertain the condition in which the nickel exists in the oil have, so far, proved abortive, but there are indications that it may be colloidal, in

which case it would act as a powerful catalyst. There are also indications that it is associated with the asphaltic portion of the oil, but this point requires further investigation. It is noteworthy in this connection, that the more asphaltic oils as a rule carry most nickel, and the solid asphalts are comparatively rich in it.

Although in all the petroleums examined the nickel appears to be in the colloidal state, this does not preclude the possibility that in some, or indeed in all oils, it may also exist in the crystalloidal condition, and since it is known that the laws of catalysts are different for each form, there exists the possibility that the presence or absence of unsaturated hydrocarbons may depend on the relative amounts of each modification present in the various oils.

In view of Hackford's theory of the formation of coil from petroleum, a number of British coals have been examined for nickel, but in one case only has the slightest trace of the metal been found, and since a second sample from the same source gave a negative result, its presence was probably adventitious. These results tend to divest this theory of its probability.

The writer has made use of the presence of nickel to show that the carbonaceous deposits in the cylinders of Diesel engines are due to the fuel rather than to the lubricating oil. These deposits provide sufficient ash to demonstrate readily the presence of the metal, even when it is difficult to detect it in the laboratory oil sample, such as in the Borneo oil previously mentioned.

Abstracted by FRANK L. HESS

Current Bibliography of Foreign Petroleum Resources[1]

H. A., "Die neuen Erdölbohrungen im Stadtgebiet von Hannover." [The New Oil Wells in Hanover.] *Ztschr. d. Internat. Vereines d. Bohring. u. Bohrtech.* (Vienna), Jg. 32, No. 13, p. 103, 1924.

BARTOSZEWICZ, STEFAN, "Reserves of Crude Oil in Poland." *Petroleum Times* (London), Vol. 12, No. 288, p. 52, 1924.

BROOKS, B. T., "Petroleum as a Chemical Raw Material." *Ind. and Eng. Chem.* (New York), Vol. 10, No. 2, pp. 185–189, 1924.

CAMERANA, ENRICO, "La zona marginale della regione petrolifera emiliana." [The Marginal Zone of the Petroleum Region of Emilia.] *La Miniera Italiana* (Rome), Year 8, No. 6, pp. 166–167, profile, 1924.

CATHERALL, A. P., "Administration Report of the Inspector of Mines for the Year 1923." Trinidad and Tobago, *Council Paper No. 41*, of 1924, 6 pp. (Port-of-Spain), 1924.

CATHERALL, A. P., "Trinidad Oil Industry." *Oil News* (London), Vol. 16, No. 607, pp. 66–67, 1924. Also: *Petroleum Times* (London), Vol. 12, No. 289, p. 87.

DAVENPORT, E. H., and COOKE, S. R., "The Oil Trusts and Anglo-American Relations." Macmillan Co., New York, 1924.

[1] Published by permission of Acting Director, U. S. Geological Survey.

DUNSTAN, A. E., THOLE, F. B., and REMFRY, F. G. P., "Bauxite as a Refining Agency for Petroleum Distillation." *Chem. and Ind.* (London), Vol. 43, No. 24, pp. 179T–188T, 1924.

FRIEDL, KARL, "Die Erdölfrage in Deutschösterreich." [The Petroleum Question in Austria.] *Ztschr. d. Internat. Ver. d. Bohring. u. Bohrtech.* (Vienna), Jg. 32, No. 14, pp. 105–110, 1924. (To be continued.)

HARDEL, J. A., "Madagascar et l'industrie pétrolière. III. Les grès bitumineux de Madagascar." [Madagascar and the Petroleum Industry. III. Bituminous Sandstones of Madagascar.] *Chim. et Ind.* (Paris), Vol. 11, No. 5, pp. 1003–1013, 1924.

HAUTPICK, E. DE, "Chemical Composition of Underground Waters a Guide to the Search for Oil with Special Reference to the Coorong Field, South Australia." *Indus. Aus. and Mng. Stand.* (Melbourne), Vol. 71, No. 1851, pp. 803–804, 1924.

HAUTPICK, E. DE, "Prospecting for Oil in Australia." *Mng. Jour.* (London), Vol. 166, No. 4637, pp. 548–550, 1924.

HOWELL, GEORGE, "The Natural Wealth of Peru." *Oil Eng. and Fin.* (London), Vol. 5, No. 99, pp. 388–392, 1924. Map.

KERN, C. E., "Persian Oil Correspondence Revealed." *Oil and Gas Jour.* (Tulsa), Vol. 23, No. 6-A, pp. 32, 130–131, 138, 1924.

KORYTKO, STEFAN, "Das Boryslawer Naphthagebiet." [The Boryslaw Oil Region.] Scale 1:15,000, Lemberg, 1924.

KORYTKO, STEFAN, "Das Karpathen Naphthagebiet." [The Carpathian Oil Region.] Scale 1:300,000, Lemberg, 1924.

NELLENSTEYN, F. J., "The Constitution of Asphalt." *Inst. Petr. Tech. Jour.* (London), Vol. 10, No. 43, pp. 311–325, 1924.

O'BRIEN, A. M., "The Technical Use of Bauxite in Connexion with Petroleum Refining." *Chem. and Ind.* (London), Vol. 43, No. 24, pp. 188T–189T, 1924.

PYHÄLÄ, EWALD, "Erwiderung an Dr. Karl Krejci, betreffend das Urgebirge und die Entstehung des Erdöles." [Reply to Dr. Karl Krejci regarding Primary Formation and Origin of Petroleum.] *Petroleum* (Berlin), Vol. 20, No. 20, pp. 972–973, 1924.

PROKOPOV, K., "The Datykhski District." *Grosnenskoe Neftianoe Khoziaistvo* (Grozny), Nos. 1–3, pp. 10–31, Jan.-Mar., 1924.

RICHARDSON, R. K., "The Geology and Oil Measures of Southwest Persia." *Oil Eng. and Fin.* (London), Vol. 5, No. 98, pp. 333–339; No. 99, pp. 401–404, 1924.

RICHARDSON, R. K., "The Geology and Oil Measures of Southwest Persia." *Inst. Petr. Tech. Jour.* (London), Vol. 10, No. 43, pp. 256–296, 1924.

SCHNABEL, EDUARD, "Die staatlichen Napthagruben von Gbely in der Slowakei (1913 bis 1922)." [The Government Petroleum Wells of Gbely in Slovakia, 1913 to 1922.] *Petroleum* (Berlin), Vol. 20, No. 18, pp. 835–850, 1924. Geol. sketch map, 7 figs.

SCHNEIDERS, GOTTFRIED, "Erfahrungen bei dem Pechelbronner Erdölzechenbetriebe." [Experiences in the Pechelbronn Petroleum Mines.] *Montan. Rundschau* (Vienna), Jg. 16, No. 12, pp. 293–298, 3 figs., 1924.

STEWART, M. M., "Oil in New Guinea." *Indus. Aus. and Mng. Stand.* (Melbourne), Vol. 71, No. 1848, p. 689, 1924.

TAKAHASHI, JUN-ICHI, "Brackish Water Shale in the Okozu Cut and Its Significance to the Petroleum Deposit." *Science Reports Tohoku Imp. Univ.* (Tokyo), Ser. 3, Vol. 2, Nos. 1–2, pp. 83–104, 2 pls., 2 text figs., 1924.

TAKAHASHI, JUN-ICHI, "On the Effect of Mineral Substances on the Thermal Decomposition of Bitumens. A Preliminary Note." *Science Reports Tohoku Imp. Univ.* (Tokyo), Ser. 3, Vol. 2, Nos. 1–2, pp.59–82, 11 text figs., 1924.

TAKAHASHI, JUN-ICHI, "On the So-Called Contract Phenomena of the Tertiary Oil Measure Caused by Rhyolite in Kugami-Sarugababa Region, Province of Echigo, Japan." *Science Reports Tohoku Imp. Univ.* (Tokyo), Ser. 3, Vol. 2, Nos. 1–2, pp. 39–58, 2 pls., 1924.

VOITESTI, I. P., "Rapports géologiques entre les gisements de sel et ceux de pètrole." [Geologic Relations between Salt and Petroleum Deposits.] *Ann. d. Mines de Roumanie* (Bucharest), Year 7, No. 12, pp. 361–369, 1924.

VYSHETRAEVSKI, S., "Investigations of the Kuban-Chernomorsk Region and Its Petroleums." *Groznenskoe Neftânoe Khozâistvo* (Grozny), Nos. 1–3 (21–23), pp. 44–61, Jan.-Mar., 1924. (In Russian.)

WADE, ARTHUR, "The Oil Shales of Tasmania—Recent Developments." *Oil News* (London), Vol. 16, No. 606, pp. 37–38, 1924.

WILSON, W. J., "The Crude Oils of Burmah and Assam." *Inst. Petr. Tech. Jour.* (London), Vol. 10, No. 43, pp. 227–255, 1924.

ZUBER, S. R., "The Mud Volcano of Bibi-Eibat Bay." *Azerbaidzhanskoe Neftânoe Khozâistvo* (Baku), No. 4 (28), pp. 66–67, April, 1924. (In Russian.)

ANONYMOUS, "Oil Production from Australian Coal and Shale." *Indus. Aus. and Mng. Stand.* (Melbourne), Vol. 71, No. 1845, pp. 580–581; No. 1846, p. 617, 1924.

ANONYMOUS, "Petroleum in China." *Petroleum Times* (London), Vol. 12, No. 290, p. 132, 1924.

ANONYMOUS, "The Oil Prospects of Ecuador." *Petroleum Times* (London), Vol. 12, No. 289, p. 88, 1924.

ANONYMOUS, "The Oil Shale of Esthonia." *Petroleum Times* (London), Vol. 11, No. 285, pp. 883–884, map of concessions, 1924.

ANONYMOUS, "Some Dry Holes and More than a Million Dollars Left When Standard Quits Island [Philippines]." *The Oil Weekly* (Houston), Vol. 34, No. 3, p. 64, 1924.

ANONYMOUS, "Le capital étranger dans l'industrie roumaine du pétrole." [Foreign Capital in the Rumanian Petroleum Industry.] *Moniteur du Pétrole Roumain* (Bucharest), Vol. 23, No. 13, pp. 1021–1022, 1924.

ANONYMOUS, "La production d'asphalte brut de la Roumanie (en kilogrammes) en 1923." [The Production of Crude Asphalt in Rumania (in kilograms) in 1923.] *Ann. d. Mines de Roumanie* (Bucharest), Year 7, No. 12, pp. 378–379, 1924.

ANONYMOUS, "Die Asphaltindustrie der Schweiz." [The Swiss Asphalt Industry.] *Petroleum* (Berlin), Vol. 20, No. 20, p. 976, 1924.

ANONYMOUS, "The Search for Oil: Oil-bearing Sands Discovered at Orallo." *Queensland Govt. Mng. Jour.* (Brisbane), Vol. 25, No. 288, p. 175, 1924.

ANONYMOUS, "Stagnant Sea Areas Supposed Source of Petroleum Basins." *Oil and Gas Jour.* (Tulsa), Vol. 23, No. 8-A, pp. 86, 90, 1924.

ANONYMOUS, "Tar Sand Mountain in Northern Alberta." *Oil and Gas Jour.* (Tulsa), Vol. 23, No. 7-A, p. 84, 1924.

ANONYMOUS, "The Oilfields of Trinidad." *Oil Eng. and Fin.* (London), Vol. 5, No. 99, pp. 393–398, 1924.

ANONYMOUS, "Prospects for Oil in Victoria." *Indus. Aus. and Mng. Stand.* (Melbourne), Vol. 71, No. 1853, p. 892, 1924.

BERTRAND L. JOHNSON[1]

[1] Assisted by Miss L. M. Jones and Miss M. F. McShea.

THE ASSOCIATION ROUND TABLE

PACIFIC COAST MEETING OF PETROLEUM GEOLOGISTS

An informal account of the meeting of Pacific Coast petroleum geologists in Los Angeles, September 26 and 27, has been received from Frank S. Hudson, Pacific Coast regional director of the American Association of Petroleum Geologists, and E. G. Gaylord, vice-president of the Association. Since the profession at large is interested in this gathering, the *Bulletin* takes pleasure in publishing a record of the proceedings.

The general plan of the meeting was essentially similar to those of the American Association, the chief part of the program consisting of technical sessions at which a number of discussion-provoking papers were presented, most of them probably to be offered later in these pages. Attendance at the technical meetings reached a maximum of about 130. Short business sessions were held for the purpose of effecting a permanent organization and later for the election of officers. On Friday evening, September 26, a very pleasant dinner was enjoyed at the Hotel Alexandria.

The program of papers presented at the technical sessions was as follows:

Age and Correlation of the Kreyenhagen Shale in California ..... G. D. Hanna
Thrust Faulting in the Region of Mount Diablo ..... Bruce L. Clark
The Unconformity between the Santa Margarita and Monterey Formations in the Salinas Valley ..... R. D. Reed
Structural Problems in Southern California ..... W. S. W. Kew
Notes on Geology of Baldwin Hills Region ..... A. J. Tieje
The Wheeler Ridge Oil Field ..... George Cunningham
Geology and Well Products of the Tzeliutsing District, Szechuan, China ..... G. D. Louderback
The Study of Sub-surface Formations in California Oil-Field Development ..... C. D. Hanna, H. L. Driver
Interpretation of Core Samples ..... Curtice and Henderson
Geochemical Relations of California Oil Field Waters ..... Chase Palmer
Chloride Oil Field Waters—Ventura County ..... N. L. Taliaferro, F. S. Hudson
The Elements of the Oil-Well Spacing Problem ..... L. C. Uren
Emulsion Breaking—Celite Process ..... J. L. Chase
Chinese Methods of Well-Drilling and of Handling Brines and Gas ..... G. D. Louderback
Automatic Feed for Rotary Drilling ..... F. W. Hild
"Oil Well" Hild Differential Drive ..... Lester H. Keim

After the election of F. S. Hudson as temporary chairman, a committee on organization was appointed, consisting of R. E. Collom, chairman, J. B. Case, G. C. Gester, Robert Moran, and N. L. Taliaferro. The committee proposed the organization of a "Pacific Society of Petroleum Geologists" and offered a draft of a constitution which was adopted. S. H. Gester was elected chairman, and R. R. Morse, secretary-treasurer of the newly formed society. Preparation of a petition to the American Association of Petroleum Geologists for admission as a regional section of that association was authorized.

At the dinner, Joseph Jensen acted as toastmaster. The principal speaker was Mr. A. E. Morgan, president of Antioch College, Ohio, who discussed the necessity for broader curricula in technical colleges. E. G. Gaylord spoke on the subject of shyster geologists, and J. M. Sands gave an account of the history of the American Association of Petroleum Geologists. One hundred and one people were present.

CONSTITUTION

PACIFIC SOCIETY OF PETROLEUM GEOLOGISTS

Article I. Name

The name of this society shall be The Pacific Society of Petroleum Geologists.

Article II. Membership

Section 1. Any active or associate member of the American Association of Petroleum Geologists, in good standing, and now resident in California, Oregon or Washington, shall be eligible to membership in this society comparably as active or associate member.

Sec. 2. Payment of annual dues of this society by any person, qualified as in Section 1 above, shall be deemed to be a declaration of membership, in this society.

Article III. Object

The object of this society shall be to provide for discussion of subjects and problems coming within the scope of the profession and, by such intercourse, to promote the advancement and aims of The American Association of Petroleum Geologists as set forth in Article II of its constitution.

Article IV. Officers

Section 1. The officers of this society shall be a chairman and a secretary-treasurer, who shall assume the duties of their respective offices at the first of the calendar year following their election as hereinafter provided. Their terms of office shall be for one year.

Sec. 2. The officers of this society shall be elected by the membership present at the annual meeting.

Sec. 3. There shall be an executive committee consisting of the chairman, secretary-treasurer, retiring chairman and two active members appointed by the chairman.

Article V. Dues

The dues of this society shall be $1.00 per year, due and payable in advance at the beginning of each calendar year.

ARTICLE VI. MEETINGS

SECTION 1. Meetings shall be held annually.

SEC. 2. The time and place of the annual meeting shall be determined by the executive committee.

SEC. 3. The membership shall be notified of the time and place of the annual meeting at least three months prior to the date determined by the executive committee.

ARTICLE VII. AMENDMENTS

This constitution may be amended by a two-thirds vote of all active members present at an annual meeting or by a mail ballot sent to the active membership.

Mr. Morse reports the following list of those in attendance at the meeting of the Pacific Society of Petroleum Geologists, Los Angeles.

Members: Elmer R. Ames, Irving V. Augur, Roy M. Barnes, Reed D. Bush, W. R. Calvert, J. B. Case, James L. Chase, Roy E. Collom, William W. Copp, Willard W. Cutler, Jr., Walter A. English, R. N. Ferguson, Douglas Fyfe, E. G. Gaylord, G. C. Gester, S. H. Gester, G. D. Hanna, Frank S. Hudson, Emile Huguenin, Joseph Jenson, Harry R. Johnson, W. S. W. Kew, B. L. Laird, Edward D. Lynton, A. S. McCullough, F. C. Merritt, Robert B. Moran, Frank Morgan, Roy R. Morse, E. D. Nolan, C. B. Osborne, R. M. Overbeck, J. R. Pemberton, Ralph D. Reed, J. M. Sands, Walter Stalder, Ben Stroud, George O. Suman, Jr., Joseph A. Taff, N. L. Taliaferro, H. B. Thomson, C. G. Thoms.

Associate members: Glenn H. Bowes, Thomas W. Buzzo, Harold V. Dodd, Harold W. Hoots, Earl B. Noble, Rudolf R. Pollak, Earl M. Price, Thomas F. Stipp.

Guests: Z. H. Bissell, Lot Bowen, T. K. Bowles, C. H. Bowling, R. R. Brandenthaler, H. A. Brett, Chester Cassel, J. A. Collins, William Comstock, Grant W. Corby, R. D. Copley, Bruce Clark, George M. Cunningham, Roy S. Curl, A. A. Curtice, G. H. Doane, J. J. Doolittle, H. L. Driver, M. G. Edwards, E. C. Edwards, H. H. Fentous, C. S. Franklin, H. A. Goode, Paul P. Goudkoff, M. A. Grizzle, W. W. Heathman, Ben F. Hake, H. G. Henderson, Paul L. Henderson, A. L. Holston, R. L. Keyes, W. D. Kleinpell, Emil Kluth, Thomas L. Koch, V. N. Jurin, M. E. Lake, George W. LaPeine, Harvey W. Lee, George D. Louderback, S. H. Marshall, R. E. McCabe, D. S. McPhee, Chase Palmer, H. K. Pieper, L. E. Porter, N. A. Rousselot, Theodore K. Sawyer, C. R. Swarts, T. E. Swigart, A. J. Tieje, C. F. Tolman, Lester C. Uren, K. L. Vanderahe, T. Vandergrautz, M. Van Couvering, H. P. Vickery, V. H. Wilhelm, C. G. Willis.

EDITOR

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This publication does not constitute an election, but places the names before the membership

at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to Charles E. Decker, Norman, Oklahoma.

(Names of sponsors are placed beneath the name of each applicant.)

FOR FULL MEMBERSHIP

John M. Alden, Denver, Colorado
E. P. Campbell, W. W. Scott, Charles M. Rath
Nathan W. Bass, Lawrence, Kansas
K. C. Heald, W. W. Rubey, David White
Frederick Frei, Dallas, Texas
Roscoe E. Shutt, Angus McLeod, W. van Holst Pellekaan
Ellis A. Hall, Boulder, Colorado.
Charles M. Rath, Charles T. Lupton, Harold T. Morley
John S. Ivy, Shreveport, Louisiana
F. W. DeWolf, W. C. Spooner, A. F. Crider
William D. Kleinpell, San Francisco, California
R. E. Collom, Carl H. Beal, R. M. Barnes
George L. Klingaman, San Francisco, California
G. C. Gester, S. H. Gester, Roy R. Morse
Gordon W. Lepper, Rangoon, Burma
Wallace Lee, A. L. Beekly, Richard Hughes
George D. Louderback, Berkeley, California
S. H. Gester, N. L. Taliaferro, Frank S. Hudson
Robert L. Marston, Maracaibo, Venezuela
Louis A. Scholl. Jr., James T. Duce, Arthur E. Stander
Helen M. Martin, Tulsa, Oklahoma
J. W. Merritt, L. M. Neumann, S. Weidman
Laurence A. Ogden, Bartlesville, Oklahoma
V. E. Swigart, M. J. Kirwan, A. W. Ambrose
James H. Page, Iola, Kansas
F. L. Aurin, Henry A. Ley, Everett Carpenter
Arthur E. Remington, Maracaibo, Venezuela
Louis A. Scholl, Jr., James T. Duce, Arthur E. Stander
Waldo E. Rennie, Denver, Colorado
Thomas S. Harrison, Victor J. Hendrickson, Clarence B. Osborne
William L. Stryker, Fredonia, Kansas
W. H. Twenhofel, Wm. L. Ainsworth, Charles N. Gould
Arthur J. Tieje, Los Angeles, California
N. L. Taliaferro, F. S. Hudson, William S. W. Kew
Frederick B. Tough, Washington, D. C.
M. J. Kirwan, A. W. Ambrose, L. C. Snider
Earl W. Wagy, San Francisco, California
R. E. Collom, R. W. Pack, S. H. Gester

FOR ASSOCIATE MEMBERSHIP

Albert L. Ackers, Colorado, Texas
Claude F. Dally, O. C. Harper, Leonard W. Orynski
Lot Bowen, Los Angeles, California
William S. W. Kew, Hoyt S. Gale, A. O. Woodford
George S. Buchanan, Tulsa, Oklahoma
A. A. Langworthy, L. Murray Neumann, Luther H. White
Harry A Godde, Santa Paula, California
J. B. Case, R. N. Ferguson, R. E. Collom
Lawrence R. Hagy, Oklahoma City, Oklahoma
J. V. Howell, Wallace C. Thompson, A. J. Williams
Richard C. Harris, Los Angeles, California
Jack M. Sickler, James M. Douglas, E. Russell Lloyd
Roy T. Hazzard, Colorado, Texas
Claude F. Dally, O. C. Harper, Leonard W. Orynski
Merle C. Israelsky, Houston, Texas
Donald C. Barton, Wallace E. Pratt, F. B. Plummer
Carl E. Johnson, Salt Lake City, Utah
W. R. Calvert, Christion Vrang, Glen M. Ruby
Huylar W. Lee, Colorado, Texas
G. C. Gester, S. H. Gester, Leonard W. Orynski
Roscoe E. McCabe, Santa Maria, California
Clarence B. Osborne, R. E. Collom, Walter A. English
Orlando G. McDonald, Denver, Colorado
J. W. Merritt, John M. Herald, Frank A. Herald
Robert McNeely, Ponca City, Oklahoma
V. E. Monnett, S. Weidman, H. C. George
Clifford L. Mohr, Denver, Colorado
W. Grant Blanchard, Jr., Jack M. Sickler, Alex W. McCoy
Lowell K. Mower, Portland, Maine
S. W. Wells, K. H. Schilling, R. W. Clark
Werner Tappolet, Tulsa, Oklahoma
Frederic H. Lahee, R. S. McFarland, O. M. Edwards
Cyril B. Taylor, Tulsa, Oklahoma
D. P. Dean, Everett Carpenter, F. K. Foster
Norman E. Weisbord, Philadelphia, Pennsylvania
Dabney E. Petty, J. E. Brantly, V. E. Monnett
Rowland Gardiner Whealton, Taft, California
John F. Dodge, G. D. Hanna, J. A. Taff
Charles W. Yeakel, Maracaibo, Venezuela
Dabney E. Petty, J. E. Brantly, Alfred Gray
Henry E. Zoller, Tulsa, Oklahoma
M. M. Valerius, Lawrence J. Zoller, Luther H. White

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The organization formerly known as the WICHITA GEOLOGICAL SOCIETY has been enlarged by vote of its members to include all geologic workers who are engaged in Kansas investigations, or who are specially interested in Kansas geology. The name of the society has been changed to the Kansas Geological Society. Its recently elected officers are W. L. AINSWORTH, Wichita, president; F. G. HOLL, El Dorado, vice-president; F. L. AURIN, Ponca City, Okla., vice-president; MARVIN LEE, Wichita, secretary. Membership in the Kansas Geological Society is restricted to those who are eligible for membership in the American Association of Petroleum Geologists.

WILLIAM S. W. KEW has recently built a new home at 1215 North Howard Street, Glendale, California, and will move there from Los Angeles.

WILLIAM A. WATKINS, who is an instructor in the department of geology at Cornell University this year, spent the field season on petroleum work in Venezuela.

R. M. OVERBECK, for some two years geologist for the Shell Company of California, left in October for La Paz, Bolivia, where he will be chief geologist for the Caracoles Tin Company.

R. R. TEMPLETON recently assumed the position of chief petroleum engineer of the Union Oil Company, Los Angeles, California. Formerly he was subsurface geologist.

THE GEOLOGISTS OF DALLAS have initiated a plan of holding regular weekly luncheons at 12:15 on Mondays, in the main dining-room of the Adolphus Hotel. These luncheons are entirely informal and are intended simply to give an opportunity for seeing one another and talking on any subjects of mutual interest. No special invitations are sent out, but all geologists are welcome. Geologists who are passing through Dallas and happen to be here on Mondays are cordially invited to join in these luncheons.

GEORGE I. MCFERRON, who has until recently been associated with Wood & Wood, of Tulsa, has opened an office with D. G. Renfro, of New Castle, Pennsylvania, at Independence, Kansas.

W. E. WRATHER has recently returned to his house in Dallas, where he intends to reside. This is of interest to his many geologist friends in the Mid-Continent.

THORNTON DAVIS, Harvard '15, joined the Simms Oil Company geological force about August 1, and is at their Wichita Falls office. He was for three years in Africa with the Sinclair Oil Company, returning about a year ago. Until he joined the Simms Company he was engaged in petroleum work in Alabama.

EARL B. NOBLE has recently been appointed geologist in charge of the San Joaquin Valley and coastal districts for the Union Oil Company of California.

HAROLD W. HOOTS has been engaged this summer and fall in detailed mapping of the southern part of San Joaquin Valley, including Wheeler Ridge, for the U. S. Geological Survey.

C. F. TOLMAN, professor of geology at Stanford University, is on leave this quarter from the university and is engaged in field work in Santa Barbara County, California, for an oil company.

During the past year the GULF CORPORATION has been conducting geological investigations in California, with headquarters in the Union Oil Building, Los Angeles, under the direction of HOYT S. GALE. Associated with him are E. L. ICKES, W. S. W. KEW, LOT BOWEN, and T. W. KOCH. A. E. WALLACE, previously with the Gypsy Oil Company at Tulsa, Oklahoma, has been in Los Angeles for a somewhat longer time engaged in keeping the eastern offices informed as to the oil situation in California. No lands have yet been leased by the company, the work being mainly to determine the prospects for future production in this state.

R. P. MCLAUGHLIN has been quite ill with scarlet fever.

M. G. EDWARDS, until recently connected with the geological department of the University of California, has joined the geologic staff of the Shell Company of California.

RALPH D. REED, who received his Doctor's degree from Stanford University recently, is working for the Marland Oil Company, of California, making a detailed study of the coast range region in the Coalinga and Sunset districts.

K. H. SCHILLING, of the Roxana Petroleum Corporation, has been transferred from the Tulsa office to Okmulgee to do subsurface work in that area.

E. G. COLTON has recently resigned from the staff of the Roxana Petroleum Corporation in the Okmulgee district and accepted a position with the Sinclair Oil and Gas Company in charge of their geological work at Okmulgee.

C. A. WARNER, Houston Oil Company geologist, in charge of the Okmulgee office, has been spending most of his time the past month in the Cromwell pool, where his company is drilling two wells.

JESS VERNON, geologist for the Amerada Petroleum Corporation at Okmulgee, is passing the cigars in honor of a young daughter, Martha Helen, born September 26, 1924.

R. W. CLARK has recently returned from Michigan, where he spent the summer. Mr. Clark received his Ph.D. degree in June from the University of Michigan.

F. M. VAN TUYL, professor of geology at the Colorado School of Mines, is giving a course on oil geology at the Y.M.C.A., the course this year being a repetition of the one given by him last year.

E. L. JONES, Jr., chief geologist for the Comar Oil Company, with offices at Ponca City, Oklahoma, was a recent visitor in Denver.

JOHN D. NORTHROP spent a day in Denver a few weeks ago, en route from Wyoming to Washington, D.C. Mr. Northrop is chief of the Division of Mineral Land Classification for the U. S. Geological Survey.

ROBERT H. WOOD, consulting geologist, of Tulsa, Oklahoma, spent several days in Colorado recently.

MARTIN J. GAVIN, with the U. S. Bureau of Mines at San Francisco, stopped in Denver recently on his way to Washington, D.C.

W. T. NIGHTINGALE, geologist, of Seattle, Wyoming, spent several weeks in Colorado on business and has just returned to Seattle.

GUY E. MILLER, geologist for the Shell Company of California, with headquarters in Los Angeles, spent his vacation in the vicinity of Denver and Canon City, the latter being his former home.

ALFRED R. SCHULTZ, of Hudson, Wisconsin, visited in Denver for a few days, coming here from southwestern Wyoming, where he made some examinations for the Union Pacific Coal Company.

A. T. SCHWENNESEN, who has been in charge of geologic work for the Royal Dutch Shell interests in the Rocky Mountain region for the past six months, has been transferred to Houston, Texas, to look after Gulf Coast work for the Roxana Petroleum Corporation.

VERGIL N. BROWN, who has been working in the Rocky Mountain region for the Danciger Oil Company, has severed his connection with that company and returned to Tulsa.

MAX W. BALL, accompanied by Mrs. Ball, has recently returned from a trip to the Western Slope, where he visited all of the drilling wells in western Colorado and eastern Utah.

At the October 16 meeting of the ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS, Max W. Ball urged members of the association to frame and display their copies of the code of ethics, as a step toward protecting the public against inadequately trained and unscrupulous geologists. He also spoke on ethics before a meeting of the Sigma Gamma Epsilon fraternity of the Colorado School of Mines, using the code of the association as a basis, and a week later made a similar talk to the Geological Club of the University of Colorado, at Boulder.

C. H. WEGEMANN, chief geologist for the Midwest Refining Company, returned to Denver about October 1, after a two months' trip visiting the field parties of the company in Colorado, Wyoming, Montana, and Canada.

C. MAX BAUER, chief geologist of the Mid-Northern Oil Company at Billings, Montana, has written a paper for the November issue of *Mining and Metallurgy*, entitled "The Lake Basin Oil Field of Montana."

C. B. OSBORNE, consulting geologist, of Los Angeles, has made two recent field trips to Colorado and Rocky Mountain territory on geological examinations.

E. G. ROBINSON, geologist for the Midwest Refining Company at Billings, Montana, has taken up advanced studies in geology at Cornell University.

JOHN G. BARTRAM, geologist of the Midwest Refining Company at Casper, Wyoming, has written a paper for the November issue of *Mining and Metallurgy* entitled "Oil Possibilities of Southern Wyoming."

E. B. HOPKINS, consulting geologist, of New York City, recently visited in Denver, en route to New Mexico, where his clients have developed production of very high grade oil on the Rattlesnake dome, near Shiprock.

JOHN H. WILSON is in charge of the subsurface laboratory and the subsurface investigation being conducted by the Midwest Refining Company.

Among Tulsa geologists who inspected the Colorado oil fields during the summer were: J. W. MERRITT, W. EDWARD BLOESCH, W. Z. MILLER, and M. M. VALERIUS. S. S. PRICE spent a good portion of the summer in the Adirondacks.

E. G. WOODRUFF has recently been engaged in consulting work in western and southern Kansas.

MRS. FANNY C. EDSON is doing microscopic and paleontological work for the Roxana Petroleum Company in the Tulsa office.

F. K. FOSTER is in charge of the Sinclair interests in Kansas, with offices at Winfield, Kansas.

HERBERT G. OFFICER, formerly with the Twin States Oil Company in Tulsa, has charge of the northwestern Oklahoma division of the Sinclair Oil Company, with offices at Enid, Oklahoma.

VIRGIL O. WOOD is credited with mapping the structure in Sec. 32, T. 15 N., R. 5 E., Oklahoma, on which Morgan and Flynn recently opened a new pool. The south part of the structure was originally worked by W. Z. MILLER.

J. C. ROSS has resigned his position with the Twin States Oil Company, and is now doing geological work for private interests.

J. N. MCGIRL, formerly with the Pure Oil Company in Venezuela, has joined the firm of Wood and Wood, consulting geologists.

LEWIS G. WEEKS, recently returned from four years' geological investigation abroad for the Whitehall Petroleum Corporation, Ltd., of London, has now undertaken work for the Standard Oil Company of New Jersey and has again gone abroad. His address is Room 322, 26 Broadway, New York.

EDWIN T. HODGE, professor of economic geology, University of Oregon, spent the last summer in a study of the structure of the coast ranges and the condition under which their sedimentary rocks were formed. This study was made with special reference to the possibility of the occurrence of petroleum.

In this column of the July-August *Bulletin*, an item appeared stating that MAX W. BALL, a member of the board of trustees of the Colorado School of Mines, had been active in establishing a professorship in oil-shale mining and refining at the school, and that BARNABAS BRYAN, of New York, had been secured to head this department. Mr. Ball informs us that this information is erroneous. The school established an associate professorship in petroleum engineering for the purpose of teaching present-day production methods, and P. F. SHANNON, of Lance Creek, Wyoming, formerly Wyoming and Montana field superintendent for the Continental Oil Producing Company, was selected to fill the position. Refining methods are taught by R. C. BECKSTROM, head of the department. There is no intention of creating an oil-shale professorship.

INDEX TO VOLUME VIII

PAGE

American Petroleum Institute, Representation in the. By Max W. Ball. The Association Round Table 101
Annual Meeting in Wichita, Kansas, Next. By James H. Gardner. The Association Round Table 530
Associate Editors, For the Encouragement and Guidance of. By Max W. Ball. The Association Round Table 99
Association Round Table, The 99, 261, 362, 530, 685, 838
At Home and Abroad 131, 264, 398, 535, 691, 843
Aurin, F. L., G. C. Clark and. The Tonkawa Field, Oklahoma . . 269
Australia, Exploration for Oil in. Geological Note by Jon A. Udden . 244
Avery's Island, Sandstone Inclusion in Salt in Mine on. Geological Note by K. C. Heald 674

Ball, Max W. For the Encouragement and Guidance of Associate Editors. The Association Round Table 99
———. Gas near Fort Collins, Colorado. Geological Note . . . 79
———. Let's Talk of Houston. The Association Round Table . . 99
———. Representation in the American Petroleum Institute. The Association Round Table 101
Barnes, R. M., R. E. Collom and. California Oil Production and Reserves 212
Bentonite in the Upper Cretaceous of Louisiana. Geological Note by M. N. Bramlette 342
Birk, R. A. The Sayre Field, Beckham County, Oklahoma. Geological Note 347
"Black Shale" Formation in and about Chesapeake Bay. By Marcus I. Goldman 195
Bramlette, M. N. Bentonite in the Upper Cretaceous of Louisiana. Geological Note 342
———. Volcanic Rocks in the Cretaceous of Louisiana. Geological Note 344
Brantly, J. E. Résumé of the Geology of the Gulf Coastal Plain . . 21
Brown, I. O., D. S. Hager and. The Minerva Oil Field, Milam County, Texas 632
Burbank Field, Osage County, Oklahoma. By J. M. Sands . . . 584

California, A Section of the Monterey (Salinas) Shales in Pine Canyon, Monterey County. By Walter Stalder 55
California, Dynamics of Oil-Field Structure in Southern. By R. N. Ferguson and C. G. Willis 576

PAGE

California, Early Oil Development in. By W. W. Orcutt 61
California, Huntington Beach Oil Field, Orange County. By S. H. Gester 41
California Members of the American Association of Petroleum Geologists, To the. By The Arrangement Committee 532
California Men Active. By James H. Gardner. The Association Round Table 532
California Oil Fields, Southern, New Development Problems and Their Solution in. By Joseph Jensen and Glenn D. Robertson . . . 135
California Oil Fields, The Rôle of the Geologist in the Development of the. By Robert B. Moran 73
California Oil Production and Reserves. By R. E. Collom and R. M. Barnes 212
California, Oil Shale in Santa Barbara County. By F. D. Gore . . 459
California Oil Situation, A Study of the Present. By Joseph Jensen . 1
California Petroleums, Chemical Characteristics of. By Paul W. Prutzman 560
California, Santa Fe Springs Field. By R. R. Templeton and C. R. McCollom 178
California State Mining Bureau. The Minor Oil Fields of Kern County. Review by William S. W. Kew 833
California, The Oil Fields of Ventura County. By N. L. Taliaferro, F. S. Hudson, and U. N. Craddock 789
Canada, Developments at Fort Norman, Mackenzie District. Geological Note 511
Carbon Dioxide from Wells in Colorado. Geological Note by James Terry Duce 831
Carbon Ratios of Cretaceous Coals in New Mexico in Their Possible Relation to Oil. Geological Note by Willis Storm 519
Certificate of Incorporation of the American Association of Petroleum Geologists. The Association Round Table 391
Chemical Characteristics of California Petroleums. By Paul W. Prutzman 560
Chesapeake Bay, "Black Shale" Formation in and about. By Marcus I. Goldman 195
China, The Oil Fields of. By T. O. Chu 169
Chu, T. O. The Oil Fields of China 169
Clapp, Frederick G. Notes on Natural Gas Fields of Transylvania, Roumania 202
Clark, G. C., and F. L. Aurin. The Tonkawa Field, Oklahoma . . 269
Coast Region, A Revision of the Texas Tertiary Section with Special Reference to the Oil-Well Geology of the. By E. T. Dumble . 424
Collom, R. E., and R. M. Barnes. California Oil Production and Reserves 212

PAGE

Collom, C. R., R. R. Templeton and. Santa Fe Springs Field, California 178
Colorado, Gas near Fort Collins. Geological Note by Max W. Ball . 79
Constitution of the American Association of Petroleum Geologists, The. The Association Round Table 393
Correlative Value of the Heavy Minerals, The. By F. G. Tickell . 152
Cotton Valley Oil and Gas Fields, Webster Parish, Louisiana. Geological Note by Sidney Powers 244
Craddock, U. N., N. L. Taliaferro, F. S. Hudson and. The Oil Fields of Ventura County, California 787
Cretaceous of Louisiana, Volcanic Rocks in the. Geological Note by M. N. Bramlette 344
Crider, A. F. Volcanic Ash in Northern Louisiana. Geological Note . 525
Cuba, The Jurassic as a Source of Oil in Western. Geological Note by Albert Wright, Jr., and P. W. K. Sweet 516
Current Bibliography of Foreign Petroleum Resources. Review by Bertrand L. Johnson 251, 352, 678, 835
Cushman, Joseph A. The Use of Foraminifera in Geologic Correlation . 485

Decker, C. E. Membership Applications Approved for Publication. The Association Round Table . . . 104, 261, 386, 530, 688, 840
Dielectric Mineral Separation: Notes on Laboratory Work. By Bernard W. Holman and St. J. R. C. Shepherd. Review by Marcus I. Goldman 682
Dielectric Separation: a New Method for the Treatment of Ores. By H. S. Hatfield. Review by Marcus I. Goldman 682
Direct Synthesis of Higher from Lower Hydrocorbons. Geological Note by W. T. Thom, Jr. 830
Distribution of Membership in the American Association of Petroleum Geologists. By Raymond C. Moore. The Association Round Table 390
Donoghue, David. Absence of Metamorphosed Sedimentary Rocks in the Texas Panhandle. Geological Note 241
Dubendorf, H. H., A. T. Schwennesen, R. M. Overbeck and. The Long Beach Oil Field and Its Problems 403
Duce, James Terry. Carbon Dioxide from Wells in Colorado. Geological Note 831
Dumble, E. T. A Revision of the Texas Tertiary Section with Special Reference to the Oil-Well Geology of the Coast Region . . . 424
Dynamics of Oil-Field Structure in Southern California. By R. N. Ferguson and C. G. Willis 576

Ely, Fred B. Concerning Theories. Discussion 94
English, Walter A. Some Planetable Methods 47
Estabrook, E. L. Occurrences of Oil and Gas in Wyoming. Geological Note 515

PAGE

Ferguson, R. N., and C. G. Willis. Dynamics of Oil-Field Structure in Southern California 576
Foraminifera for Stratigraphy, Smaller. Geological Note by G. Dallas Hanna 246
Foraminifera, The Use of, in Geologic Correlation. By Joseph A. Cushman 485
Foreign Petroleum Resources, Current Bibliography of. Review by Bertrand L. Johnson 251, 352, 678, 834
Fort Collins, Colorado, Gas near. Geological Note by Max W. Ball . 79
Fort Norman, Mackenzie District, Canada, Developments at. Geological Note 511
Gardner, James H. A Mid-Year Meeting in 1924. The Association Round Table 385
———. California Men Active. The Association Round Table . . 532
———. Next Annual Meeting in Wichita, Kansas. The Association Round Table 530
———. Regional Directors. The Association Round Table . . . 390
Gas near Fort Collins, Colorado. Geological Note by Max W. Ball . 79
Gas Well, Large, in Jim Hogg County, Texas. Geological Note by Richard A. Jones 676
Gavin, Martin J. Oil Shale, An Historical, Technical, and Economic Study. Review by Dean E. Winchester 529
Gaylord, E. G., and J. A. Taff. Geological Organization of an Oil Company 651
Geologic Correlation, The Use of Foraminifera in. By Joseph A. Cushman 485
Geologic Work, Use of the Sketching Case in. Geological Note by G. A. Waring 672
Geological Features Illustrated by Models. Geological Note by L. G. Huntley 89
Geological Map of Oklahoma, New. Geological Note by Sidney Powers 240
Geological Notes 79, 240, 342, 511, 669, 830
Geological Organization of an Oil Company. By E. G. Gaylord and J. A. Taff 651
Geologists-International Petroleum Show. By Frank C. Greene. The Association Round Table 685
Geology, Areal, of a Part of Southwestern Oklahoma. By Roger W. Sawyer 312
Geology of the Gulf Coastal Plain, Résumé of the. By J. E. Brantly . 21
Gester, S. H. Huntington Beach Oil Field, Orange County, California 41
Goldman, Marcus I. "Black Shale" Formation in and about Chesapeake Bay 195
———. Review of Dielectric Mineral Separation: Notes on Laboratory Work, by Bernard W. Holman and St. J. R. C. Shepherd . . 682

PAGE

Goldman, Marcus I. Review of Dielectric Separation: a New Method for the Treatment of Ores, by H. S. Hatfield 682
Golfo de San Jorge, Lineas Generales de la Constitución Geológica de la Región situada al Oeste del. By Anselmo Windhausen. Review by F. H. Lahee 684
Gore, F. D. Oil Shale in Santa Barbara County, California . . . 459
Gould, Charles N. A New Classification of the Permian Redbeds of Southwestern Oklahoma 322
Graham Field, Oklahoma, The. By C. W. Tomlinson and Willis Storm 593
Green River Formation, The Origin of the. By Junius Henderson . 662
Greene, Frank C. Geologists-International Petroleum Show. The Association Round Table 685
Gulf Coastal Plain, Résumé of the Geology of the. By J. E. Brantly . 21

Hager, D. S., and I. O. Brown. The Minerva Oil Field, Milam County, Texas 632
Hanna, G. Dallas. Smaller Foraminifera for Stratigraphy. Geological Note 246
Hatfield, H. S. Dielectric Separation: a New Method for the Treatment of Ores. Review by Marcus I. Goldman 682
Heald, K. C. Contribution to Stratigraphy of Western Kansas. Geological Note 242
———. Oil Geology and Science 473
———. Review of the Study and Correlation of Sediments by Petrographic Methods, by Henry C. Milner 97
———. Sandstone Inclusion in Salt in Mine on Avery's Island. Geological Note 674
Heavy Minerals, The Correlative Value of the. By F. G. Tickell . 152
Henderson, Junius. The Origin of the Green River Formation . . 662
Hess, Frank L. Review of The Significance in Petroleum, by William Ramsay 832
Höfer, Hans von: Obituary. By Adam Wroblewski 534
Holman, Bernard W., and St. J. R. C. Shepherd. Dielectric Mineral Separation: Notes on Laboratory Work. Review by Marcus I. Goldman 682
Hosterman, J. F. The Tonkawa Oil and Gas Field, Oklahoma . . 284
Houston, Let's Talk of. By Max W. Ball. The Association Round Table 99
Houston Meeting, The. By Raymond C. Moore. The Association Round Table 362
Hudson, F. S., N. L. Taliaferro, U. N. Craddock and. The Oil Fields of Ventura County, California 787
Hughes, Richard. The International Petroleum Exposition. The Association Round Table 102

PAGE

Hull, J. P. D. Plans for Compilation of Louisiana-Arkansas Geology. Geological Note 350
Huntington Beach Oil Field, Orange County, California. By S. H. Gester 41
Huntley, L. G. Geological Features Illustrated by Models. Geological Note 89

International Petroleum Exposition, The. By Richard Hughes. The Association Round Table 102

Jensen, Joseph. A Study of the Present California Oil Situation . . 1
———, and Glenn D. Robertson. New Development Problems and Their Solution in Southern California Oil Fields 135
Johnson, Bertrand L. Current Bibliography of Foreign Resources. Review 251, 352, 678, 834
Johnson, Roswell H. Oil Reserve in Teapot Dome, Wyoming. The Association Round Table 101
Jones, Richard A. Large Gas Well in Jim Hogg County, Texas. Geological Note 676
Jurassic as a Source of Oil in Western Cuba, The. Geological Note by Albert Wright, Jr., and P. W. K. Sweet 516

Kansas, Contribution to Stratigraphy of Western. Geological Note by K. C. Heald 242
Kansas, Southeast, Subsurface Observations in. By Henry A. Ley . 445
Kentucky, Northeastern Mississippi, and Tennessee, The Oil Horizons of. By Wilbur A. Nelson 621
Kentucky, Subsurface Structure of Eastern. By Gene Perry . . . 152
Kentucky-Tennessee Line, Oil Developments along the, during 1923. By Wilbur A. Nelson 454
Kern County, The Minor Oil Fields of. By the California State Mining Bureau. Review by William S. W. Kew 832
Kerogen and Its Relation to the Origin of Oil. By Earl A. Trager . . 301
Kew, William S. W. Review of the Minor Oil Fields of Kern County, by California State Mining Bureau 832
Kraus, Edgar. Logging Wells Drilled by the Rotary Method . . 641

Lahee, Frederic H. Note on the Origin of Petroleum. Geological Note 669
———. Review of Lineas Generales de la Constitución Geológica de la Región situada al Oeste del Golfo de San Jorge, by Anselmo Windhausen 684
Lane, W. C. The Importance of Water Analyses. Geological Note . 87
Ley, Henry A. Subsurface Observations in Southeast Kansas . . 445
Lineas Generales de la Constitución Geológica de la Región situada al Oeste del Golfo de San Jorge. By Anselmo Windhausen. Review by F. H. Lahee 684

PAGE

Logging Wells Drilled by the Rotary Method. By Edgar Kraus . . 641
Long Beach Oil Field and Its Problems, The. By A. T. Schwennesen, R. M. Overbeck, and H. H. Dubendorf 403
Louisiana-Arkansas Geology, Plans for Compilation of. Geological Note by J. P. D. Hull 350
Louisiana, Bentonite in the Upper Cretaceous of. Geological Note by M. N. Bramlette 342
Louisiana, Cotton Valley Oil and Gas Fields, Webster Parish. Geological Note by Sidney Powers 244
Louisiana, Northern, Volcanic Ash in. Geological Note by A. F. Crider 525
Louisiana, Volcanic Rocks in the Cretaceous of. Geological Note by M. N. Bramlette 344
Luling Oil Field in Caldwell County, Texas, The. By E. H. Sellards . 772

Melcher, A. F. Texture of Oil Sands with Relation to the Production of Oil 715
Membership Applications Approved for Publication. By C. E. Decker. The Association Round Table . . . 104, 261, 386, 530, 688, 840
Membership in the American Association of Petroleum Geologists, Distribution of. By Raymond C. Moore. The Association Round Table 390
Membership List. The Association Round Table 106
Metamorphosed Sedimentary Rocks, Absence of, in the Texas Panhandle. Geological Note by David Donoghue 241
Micro-Fossils in Petroleum Exploration, The Value of. By Charles Schuchert 539
Mid-Year Meeting in 1924, A. By James H. Gardner. The Association Round Table 385
Migration of Oil, The Effect of Pressure on the. Geological Note by E. T. Thomas 527
Migrations of Oil and Water, a Further Discussion. By E. M. Parks . 697
Milner, Henry C. The Study and Correlation of Sediments by Petrographic Methods. Review by K. C. Heald 97
Minerva Oil Field, Milam County, Texas, The. By D. S. Hager and I. O. Brown 632
Miser, Hugh D. Temperature of Oklahoma's Deepest Well. Geological Note 525
Models, Geological Features Illustrated by. Geological Note by L. G. Huntley 89
Montana, Some Notes on the Upper Cretaceous Paleogeography of. By Ernest Guy Robinson 554
Monterey (Salinas) Shales in Pine Canyon, Monterey County, California, A Section of the. By Walter Stalder 55

PAGE

Moore, Raymond C. Distribution of Membership in the American Association of Petroleum Geologists. The Association Round Table 390
———. The Houston Meeting. The Association Round Table . . 362
———. Pacific Coast Meeting of Petroleum Geologists. The Association Round Table 838
Moran, Robert B. The Rôle of the Geologist in the Development of the California Oil Fields 73

Natural Gas Fields of Transylvania, Roumania, Notes on. By Frederick G. Clapp 202
Nelson, Wilbur A. Oil Developments along the Kentucky-Tennessee Line during 1923 454
———. The Oil Horizons of Kentucky, Northeastern Mississippi, and Tennessee 621
New Mexico, Carbon Ratios of Cretaceous Coals in, in Their Possible Relation to Oil. Geological Note by Willis Storm 519
News Items. See At Home and Abroad
Nickel in Petroleum, The Significance of. By William Ramsay. Review by Frank L. Hess 833
Nowells, Kenneth B. Preliminary Report on Water Conditions in the First Wall Creek Sand, Salt Creek Oil Field, Wyoming . . . 492

Obituary: Hans von Höfer. By Adam Wroblewski 534
Oil and Gas Fields, Cotton Valley, Webster Parish, Louisiana. Geological Note by Sidney Powers 244
Oil and Gas in Wyoming, Occurrences of. Geological Note by E. L. Estabrook 515
Oil and Water, Migrations of, a Further Discussion. By E. M. Parks . 697
Oil Company, Geological Organization of an. By E. G. Gaylord and J. A. Taff 651
Oil Development, Early, in California. By W. W. Orcutt . . . 61
Oil Developments along the Kentucky-Tennessee Line during 1923. By Wilbur A. Nelson 454
Oil Field, Huntington Beach, Orange County, California. By S. H. Gester 41
Oil-Field Structure in Southern California, Dynamics of. By R. N. Ferguson and C. G. Willis 576
Oil Field, The Long Beach, and Its Problems. By A. T. Schwennesen, R. M. Overbeck, and H. H. Dubendorf 403
Oil Fields, New Development Problems and Their Solution in Southern California. By Joseph Jensen and Glenn D. Robertson . . . 135
Oil Fields of China, The. By T. O. Chu 169
Oil Fields of Kern County, The Minor. By the California State Mining Bureau. Review by William S. W. Kew 833

PAGE

Oil Fields of Ventura County, California, The. By N. L. Taliaferro, F. S. Hudson, and U. N. Craddock 787
Oil Fields, San Joaquin Valley, A Comparative Study of the. By John B. Stevens 29
Oil Fields, The Rôle of the Geologist in the Development of the California. By Robert B. Moran 73
Oil Geology and Science. By K. C. Heald 473
Oil Horizons of Kentucky, Northeastern Mississippi, and Tennessee, The. By Wilbur A. Nelson 621
Oil in Australia, Exploration for. Geological Note by Jon A. Udden . 244
Oil in Western Cuba, The Jurassic as a Source of. Geological Note by Albert Wright, Jr., and P. W. K. Sweet 516
Oil Reserve in Teapot Dome, Wyoming. By Roswell H. Johnson. The Association Round Table 101
Oil Sands, Texture of, with Relation to the Production of Oil. By A. F. Melcher 715
Oil Shale, An Historical, Technical and Economic Study. By Martin J. Gavin. Review by Dean E. Winchester 529
Oil Shale in Santa Barbara County, California. By F. D. Gore . . 459
Oil Situation, A Study of the Present California. By Joseph Jensen . 1
Oil, The Effect of Pressure on the Migration of. Geological Note by E. T. Thomas 527
Oil-Well Geology of the Coast Region, A Revision of the Texas Tertiary Section with Special Reference to the. By E. T. Dumble . . 424
Oklahoma, Burbank Field, Osage County. By J. M. Sands 584
Oklahoma, Evidences of Slumping Previous to Consolidation in the Pennsylvanian of. By Clarence S. Ross 505
Oklahoma, New Geological Map of. By Sidney Powers 240
Oklahoma, Southwestern, A New Classification of the Permian Redbeds of. By Charles N. Gould 322
Oklahoma, Southwestern, Areal Geology of a Part of. By Roger W. Sawyer 244
Oklahoma, The Graham Field. By C. W. Tomlinson and Willis Storm 593
Oklahoma, The Sayre Field, Beckham County. Geological Note by R. A. Birk 347
Oklahoma, The Tonkawa Field. By G. C. Clark and F. L. Aurin . 269
Oklahoma, The Tonkawa Oil and Gas Field. By J. F. Hosterman . 284
Oklahoma's Deepest Well, Temperature of. Geological Note by Hugh D. Miser 525
Orcutt, W. W. Early Oil Development in California 61
Overbeck, R. M., A. T. Schwennesen, H. H. Dubendorf and. The Long Beach Oil Field and Its Problems 403

Pacific Coast Meeting of Petroleum Geologists. The Association Round Table 838

PAGE
Parks, E. M. Migrations of Oil and Water, a Further Discussion . 697
Pennsylvanian of Oklahoma, Evidences of Slumping Previous to Consolidation in the. By Clarence S. Ross 505
Permian Redbeds of Southwestern Oklahoma, A New Classification of the. By Charles N. Gould 322
Perry, Gene. Subsurface Structure of Eastern Kentucky . . . 152
Petrographic Methods, The Study and Correlation of Sediments by. By Henry B. Milner. Review by K. C. Heald 97
Petroleum Exploration, The Value of Micro-Fossils in. By Charles Schuchert 539
Petroleum Exposition, The International. By Richard Hughes. The Association Round Table 102
Petroleum Geologists, Pacific Coast Meeting of. The Association Round Table 838
Petroleum, Note on the Origin of. Geological Note by Frederic H. Lahee 669
Petroleum Resources, Current Bibliography of Foreign. Review by Bertrand L. Johnson 251, 352, 678
Petroleum Show, Geologists-International. By Frank C. Greene. The Association Round Table 685
Petroleum, The Significance of Nickel in. By William Ramsay. Review by Frank L. Hess 832
Pine Canyon, Monterey County, California, A Section of the Monterey (Salinas) Shales in. By Walter Stalder 55
Planetable Methods, Some. By Walter A. English 47
Powers, Sidney. New Geological Map of Oklahoma 240
Prutzman, Paul W. Chemical Characteristics of California Petroleums 560

Ramsay, William. The Significance of Nickel in Petroleum. Review by Frank L. Hess 832
Regional Directors. By James H. Gardner. The Association Round Table 390
Redbeds, Permian, of Southwestern Oklahoma, A New Classification of the. By Charles N. Gould 322
Reviews 97, 251, 352, 529, 678, 832
Robertson, Glenn D., Joseph Jensen and. New Development Problems and Their Solution in Southern California Oil Fields . . . 135
Robinson, Ernest Guy. Some Notes on the Upper Cretaceous Paleogeography of Montana 554
———. Some Notes on Triangulation Targets. Geological Note . 512
Ross, Clarence S. Evidences of Slumping Previous to Consolidation in the Pennsylvanian of Oklahoma 505
Rotary Method, Logging Wells Drilled by the. By Edgar Kraus . . 641

PAGE

Salt Creek Oil Field, Wyoming, Preliminary Report on Water Conditions in the First Wall Creek Sand. By Kenneth B. Nowells . 492
Sands, J. M. Burbank Field, Osage County, California 584
Sandstone Inclusion in Salt in Mine on Avery's Island. Geological Note by K. C. Heald 674
San Joaquin Valley Oil Fields, A Comparative Study of the. By John B. Stevens 29
Santa Barbara County, California, Oil Shale in. By F. D. Gore . . 459
Sante Fe Springs Field, California. By R. R. Templeton and C. R. McCollom 178
Sawyer, Roger W. Areal Geology of a Part of Southwestern Oklahoma 312
Sayre Field, Beckham County, Oklahoma, The. Geological Note by R. A. Birk 347
Schuchert, Charles. The Value of Micro-Fossils in Petroleum Exploration 539
Schwennesen, A. T., R. M. Overbeck, and H. H. Dubendorf. The Long Beach Oil Field and Its Problems 403
Sediments, The Study and Correlation of, by Petrographic Methods. By Henry B. Milner. Review by K. C. Heald 97
Sellards, E. H. The Luling Oil Field in Caldwell County, Texas . . 772
Shepherd, St. J. R. C., Bernard W. Holman and. Dielectric Mineral Separation: Notes on Laboratory Work. Review by Marcus I. Goldman 682
Sidney Powers, Cotton Valley Oil and Gas Fields, Webster Parish, Louisiana. Geological Note 244
Sketching Case in Geologic Work, Use of the. Geological Note by G. A. Waring 672
Slumping, Evidences of, Previous to Consolidation in the Pennsylvanian of Oklahoma. By Clarence S. Ross 505
Southern California Oil Fields, New Development Problems and Their Solution in. By Joseph Jensen and Glenn D. Robertson . . 135
Stalder, Walter. A Section of the Monterey (Salinas) Shales in Pine Canyon, Monterey County, California 55
Stevens, John B. A Comparative Study of the San Joaquin Valley Oil Fields 29
Storm, Willis. Carbon Ratios of Cretaceous Coals in New Mexico in Their Possible Relation to Oil. Geological Note 519
———, C. W. Tomlinson and. The Graham Field, Oklahoma . . 593
Stratigraphy of Western Kansas, Contribution to. Geological Note by K. C. Heald 241
Stratigraphy, Smaller Foraminifera for. Geological Note by G. Dallas Hanna 246
Subsurface Observations in Southeast Kansas. By Henry A. Ley . 445
Subsurface Structure of Eastern Kentucky. By Gene Perry . . . 152

PAGE

Sweet, P. W. K., Albert Wright, Jr., and. The Jurassic as a Source of Oil in Western Cuba. Geological Note 516

Taff, J. A., E. G. Gaylord and. Geological Organization of an Oil Company 651
Taliaferro, N. L., F. S. Hudson, and U. N. Craddock. The Oil Fields of Ventura County, California 787
Teapot Dome, Wyoming, Oil Reserve in. By Roswell H. Johnson. The Association Round Table 101
Temperature of Oklahoma's Deepest Well. Geological Note by Hugh D. Miser 525
Templeton, R. R., and C. R. Collom. Santa Fe Springs Field, California 178
Texas, Large Gas Well in Jim Hogg County. Geological Note by Richard A. Jones 676
Texas Panhandle, Absence of Metamorphosed Sedimentary Rocks in the. Geological Note by David Donoghue 241
Texas Tertiary Section, A Revision of the, with Special Reference to the Oil-Well Geology of the Coast Region. By E. T. Dumble . . 424
Texas, The Luling Oil Field in Caldwell County. By E. H. Sellards . 772
Texas, The Minerva Oil Field, Milam County. By D. S. Hager and I. O. Brown 632
Texture of Oil Sands with Relation to the Production of Oil. By A. F. Melcher 715
Theories, Concerning. Discussion by Fred B. Ely 94
Thom, W. T., Jr. Direct Synthesis of Higher from Lower Hydrocarbons. Geological Note 830
Thomas, E. T. The Effect of Pressure on the Migration of Oil. Geological Note 527
Tickell, F. G. The Correlative Value of the Heavy Minerals . . 158
Tomlinson, C. W., and Willis Storm. The Graham Field, Oklahoma . 593
Tonkawa Field, Oklahoma, The. By G. C. Clark and F. L. Aurin . 269
Tonkawa Oil and Gas Field, Oklahoma, The. By J. F. Hosterman . 284
Trager, Earl A. Kerogen and Its Relation to the Origin of Oil . . 301
Transylvania, Roumania, Notes on Natural Gas Fields of. By Frederick G. Clapp 202
Triangulation Targets, Some Notes on. Geological Note by Ernest Guy Robinson 512

Udden, Jon A. Exploration for Oil in Australia. Geological Note . 244
Upper Cretaceous Paleogeography of Montana, Some Notes on the. By Ernest Guy Robinson 554

Ventura County, California, The Oil Fields of. By N. L. Taliaferro, F. S. Hudson, and U. N. Craddock 787
Volcanic Ash in Northern Louisiana. Geological Note by A. F. Crider 525

PAGE

Volcanic Rocks in the Cretaceous of Louisiana. Geological Note by M. N. Bramlette 344

Waring, G. A. Use of the Sketching Case in Geologic Work. Geological Note 672
Water Analyses, The Importance of. Geological Note by A. C. Lane . 87
Water Conditions in the First Wall Creek Sand, Salt Creek Oil Field, Wyoming, Preliminary Report on. By Kenneth B. Nowells . . 492
Willis, C. G., R. N. Ferguson and. Dynamics of Oil-Field Structure in Southern California 576
Winchester, Dean E. Review of Oil Shale, An Historical, Technical and Economic Study, by Martin J. Gavin 529
Windhausen, Anselmo. Lineas Generales de la Constitución Geológica de la Región situada al Oeste del Golfo de San Jorge. Review by F. H. Lahee 684
Wright, Jr., Albert, and P. W. K. Sweet. The Jurassic as a Source of Oil in Western Cuba. Geological Note 516
Wroblewski, Adam. Obituary: Hans von Höfer 534
Wyoming, Occurrences of Oil and Gas in. Geological Note by E. L. Estabrook 515
Wyoming, Preliminary Report on Water Conditions in the First Wall Creek Sand, Salt Creek Oil Field. By Kenneth B. Nowells . . 492
Wyoming, Oil Reserve in Teapot Dome. By Roswell H. Johnson. The Association Round Table 101

PROFESSIONAL DIRECTORY

ADDRESS: WILLIAM B. HEROY, ADVERTISING MANAGER, ROOM 1500,
45 NASSAU ST., NEW YORK CITY

D. DALE CONDIT
CHIEF GEOLOGIST IN INDIA
WHITEHALL PETROLEUM CORPORATION LTD.
83, THE MALL, LAHORE, INDIA
AND
53, PARLIAMENT STREET, LONDON, S.W. 1.
(NO OUTSIDE WORK)

HUNTLEY & HUNTLEY
PETROLEUM GEOLOGISTS
AND ENGINEERS
L. G. HUNTLEY — STIRLING HUNTLEY
FRICK BUILDING, PITTSBURGH, PA.

R. A. CONKLING
CONSULTING GEOLOGIST
PETROLEUM ENGINEER
COLCORD BUILDING — OKLAHOMA CITY, OKLA.

OSAGE 2049 — OSAGE 1833
GEO. C. MATSON
GEOLOGIST
408 COSDEN BLDG. — TULSA, OKLA.

JAMES L. DARNELL
ENGINEER
170 BROADWAY — NEW YORK CITY

DABNEY E. PETTY
ASSOCIATE GEOLOGIST
BUREAU OF ECONOMIC GEOLOGY
AND TECHNOLOGY
AUSTIN - - - - - TEXAS

RALPH E. DAVIS
VALUATION ENGINEER
902 PEOPLES GAS BLDG., PITTSBURGH, PENNSYLVANIA

DEWITT T. RING
PETROLEUM GEOLOGIST
EL DORADO, ARK.
905 ELECTRIC BLDG. — BUFFALO, N.Y.

FRANK W. DeWOLF
CHIEF GEOLOGIST
BOYD OIL COMPANY
NOT OPEN FOR CONSULTING ENGAGEMENTS
1322 KIRBY BUILDING — DALLAS, TEX.

EUGENE WESLEY SHAW
GEOLOGIST
170 BROADWAY
NEW YORK
302 COSDEN BLDG.
TULSA

IRVINE E. STEWART
GEOLOGIST
GREAT FALLS, MONTANA — 421 FORD BUILDING
DENVER, COLORADO — 926 PATTERSON BUILDING

FRANK A. HERALD — JOHN M. HERALD
HERALD BROTHERS
GEOLOGISTS
PETROLEUM ENGINEERS
303 COSDEN BUILDING — TULSA, OKLAHOMA

F. JULIUS FOHS
OIL GEOLOGIST
1320 KIRBY BLDG., DALLAS, TEXAS
1ST NAT. BANK BLDG., TULSA, OKLAHOMA
60 BROADWAY, NEW YORK
CABLES—FOHSOIL BENTLEY & MCNEIL—CODES
NO PROFESSIONAL WORK UNDERTAKEN

WALTER STALDER
PETROLEUM GEOLOGIST
925 CROCKER BUILDING
SAN FRANCISCO, CALIFORNIA

L. A. MYLIUS
PETROLEUM GEOLOGIST
AND ENGINEER
506 OLIVE ST.
ST. LOUIS, MO.
CHAMPAIGN, ILLINOIS

WALLACE E. PRATT
CHIEF GEOLOGIST
HUMBLE OIL AND REFINING COMPANY
HOUSTON, TEXAS

FRED H. KAY
MANAGER
VENEZUELAN SUN LTD.
CARACAS — VENEZUELA

EDWIN B. HOPKINS
CONSULTING GEOLOGIST
25 BROADWAY — NEW YORK CITY

ELFRED BECK
CONSULTING GEOLOGIST
P. O. BOX 157
225 SECURITIES BLDG.
BILLINGS - - MONTANA

JOHN B. KERR
PETROLEUM GEOLOGIST
601 BALBOA BUILDING — SAN FRANCISCO

CHARLES T. LUPTON
CONSULTING
GEOLOGIST
FIRST NATIONAL BANK BLDG.
DENVER, COLORADO

FRANK BUTTRAM
PRESIDENT
BUTTRAM PETROLEUM CORPORATION
313-314 MERCANTILE BLDG.
PHONE MAPLE 7277
OKLAHOMA CITY, OKLA.

ALFRED C. BIERMAN
GEOLOGIST AND ENGINEER
GEOLOGICAL INVESTIGATIONS
APPRAISALS—DEPLETION
FOR INCOME TAX AND COMMERCIAL PURPOSES
TELEPHONE X-3641 311 SOUTHLAND LIFE INSURANCE BUILDING DALLAS, TEXAS
ASSOCIATED WITH
CLARENCE B. OSBORNE 402 SECURITY BUILDING
LOS ANGELES CALIFORNIA

PHONE 79

I. J. BROMAN
CONSULTING GEOLOGIST
PETROLEUM AND COAL
ROUND ROCK, TEXAS P. O. BOX 440

MAX W. BALL
OIL GEOLOGIST AND ADVISER ON OIL LAND LAW
FIRST NATIONAL BANK BLDG.
DENVER, COLO.
CONSULTING PRACTICE LIMITED TO OFFICE CONSULTATION ON ROCKY MOUNTAIN MATTERS

CHESTER W. WASHBURNE
GEOLOGIST
2 RECTOR ST. NEW YORK

STUART ST. CLAIR
CONSULTING GEOLOGIST
60 WALL STREET NEW YORK CITY

BROKAW, DIXON, GARNER & McKEE
GEOLOGISTS PETROLEUM ENGINEERS
EXAMINATIONS APPRAISALS
ESTIMATES OF OIL RESERVES
120 BROADWAY NEW YORK

JOSEPH A. TAFF
CHIEF GEOLOGIST
PACIFIC OIL, ASSOCIATED OIL CO'S.
GEOLOGIST
SOUTHERN PACIFIC COMPANY
79 NEW MONTGOMERY ST. SAN FRANCISCO

W. E. WRATHER
PETROLEUM GEOLOGIST
6044 BRYAN PARKWAY
DALLAS . . . . TEXAS

J. ELMER THOMAS
CONSULTING GEOLOGIST
751 FIRST NATIONAL BANK BUILDING
CHICAGO, ILLINOIS

FREDERICK W. GARNJOST
37 WALL STREET
NEW YORK

ALEXANDER DEUSSEN
CONSULTING GEOLOGIST
SPECIALIST, GULF COAST SALT DOMES
1105-6 STATE NATIONAL BANK BLDG
HOUSTON, TEXAS

FREDERICK G. CLAPP
30 CHURCH STREET
NEW YORK

Sullivan Diamond Drills

Date From 1875

WE'VE been building Diamond Core Drills for 49 years.

Back in 1900 we were making over 20 models of Diamond Drills, and had more than 300 at work in South Africa alone, some at depths of over a mile.

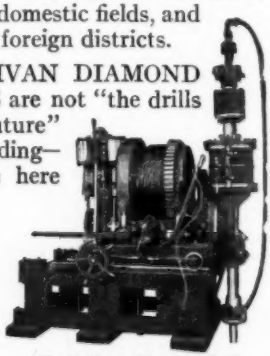
Sullivan Diamond Drills have been used in every country in the world where mining is carried on. They have located millions of dollars' worth of coal and hard mineral deposits, and have saved millions more by reporting the absence of values.

In the search for oil, Sullivan Diamond Drills are repeating this history.

They have shown their adaptability to many oil field conditions, their drilling speed and economy, and the absolute accuracy of their core findings, which are above price. They are in successful use in almost all domestic fields, and in many foreign districts.

SULLIVAN DIAMOND DRILLS are not "the drills of the future" for oil finding—they are here NOW.

Get Catalog No. 4480-o



The Sullivan Diamond Drill

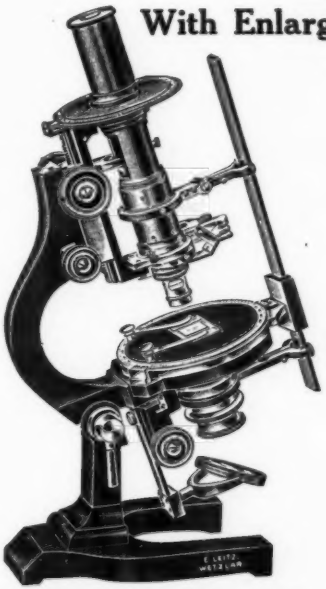
SULLIVAN MACHINERY COMPANY

127 South Michigan Avenue **Chicago**

Leitz Petrographical Microscopes

New Models

With Enlarged Field of View



Microscope "S.M" with synchronic rotation of the nicols.

These microscopes have been developed on the basis of latest suggestions from petrographists. Their novel and modern design will prove a great aid in petrographical studies.

Every leading petrographist knows the superior optical and mechanical qualities of Leitz microscopes and we therefore are fully safe if we refrain from enumerating the many features.

The variety of models we offer afford a suitable equipment for every specific requirement.

The complete assortment of our petrographical accessories will interest those who desire to add to their present equipment.

Some of the prominent features of the new model microscope are:

1. Improved Objective Clutch Changer which guarantees the objective to be permanently centered.
2. Anastigmatic Tube Analyzer which permits a most crisp definition.
3. Special Illuminating Apparatus, whereby a wider range of application is afforded.
4. Enlarged Microscope Tube which accommodates eyepieces of wide diameter, whereby the field of view is increased 50% over other types of instruments.

ASK FOR CATALOG II-B (V)

LEITZ-QUALITY OF OPTICAL AND MECHANICAL WORKMANSHIP

E. LEITZ INC. NEW YORK

LEITZ-QUALITY IS NOT SURPASSED OR EQUALLED IT IS SUPREME

60 East 10TH St.

General Distributing Agents for Canada

The J. F. Hartz Co., Ltd., Toronto, Canada

Agents for Western States—California, Washington, Oregon, Idaho, Utah, Montana and Arizona:

Spindler and Sauppé, 86 Third Street, San Francisco, Cal.